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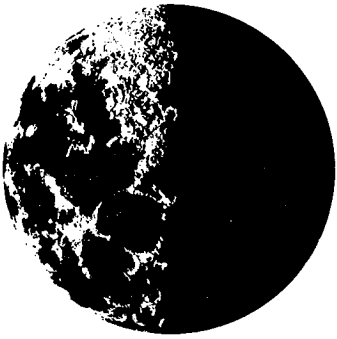
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ENGINEERING DEVELOPMENT REPORT

APOLLO PART TASK TRAINER

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16 January 1963

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Prepared by

Space and Information Systems Division
North American Aviation, Inc.,
Downey, California

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CONTENTS

Section	Page
INTRODUCTION	1
I TRAINER TASK REQUIREMENTS	3
Trainer Equipment and Systems	3
Command Module	4
Digital Computer Equipment	4
Analog Computer Equipment	11
Instructors' Console	11
Associated Support Equipment	11
Major Subsystems	13
Reliability	13
Reliability Program Considerations	13
Reliability Requirement Studies	17
Reliability Design Principles	17
II TRAINER CAPABILITIES	19
Abort Simulation	19
Special Failures	20
Reentry (Manual Mode)	20
Simulated Malfunctions	20
Malfunction Insertion	21
Display Functions	22
Detection, Isolation, and Correction	22
Evaluation Equipment	23
Crew Monitoring	23
Malfunction Control	23
Initialization of the Training Problem	23
Atmospheric Phase Initialization	24
Extra-Atmospheric Phase Initialization	24
Maintenance and Checkout	25
III SUBSYSTEM SIMULATION	27
Stabilization and Control System	27
Guidance and Navigation System	27
Orbital and Midcourse Phases	27
Launch and Reentry Phases	28
Propulsion System	28

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Section

Page

Communications and Data System	29
Environmental Control System	30
Electrical Power System	30
Launch Escape System	31
Earth Landing System	31
In-Flight Test System	32
Visual Simulation	32
Visual Related Task	32
Visual Stimuli - Response Requirements	34
Telescope and Sextant	34
Scanning Telescope (SCT) Simulation	35
Sextant (SXT) Simulation	41
Scene Generation	43
Aural Simulation	44
Other Displays and Controls	45
Separation Sequence Control	45
Radiation Warning Display	46
Caution Indication	46
In-Flight Test Control	47
Integrated Display Unit	47
Booster Situation Indicator	47
S/M Quadrant Temperature Indicator	47
Entry Monitoring Indicator	47
Lighting System	48
Rendezvous Display	48
IV MECHANIZATION EQUATIONS	49
Atmospheric Phases	49
Launch Phase Equations	49
Reentry Phase	62
Extra-Atmospheric Phases	72
Earth Orbit	75
Mid-Course Phase	78
V DESCRIPTION OF TRAINER COMPLEX	81
Computer Complex	81
Digital Computer	81
Input/Output Equipment	83
Analog Computer	84
Trainer Command Module	87
Controls and Displays	90

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Section

Page

Instructors' Station	93
Displays	98
Trainer Complex Hardware Mechanization and Integration	98

APPENDIXES

A. PRELIMINARY INSTRUCTOR AND TRAINING— TIME REQUIREMENTS	A-1
B. APOLLO SUBSYSTEMS DESCRIPTION	B-1
C. FUNCTIONAL SYSTEMS INTEGRATION	C-1

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ILLUSTRATIONS

Figure		Page
1	Apollo Part Task Trainer Facility Layout	5
2	Trainer Complex Block Diagram	7
3	Design Layout: Display Panels Arrangement	9
4	Instructors' Console	12
5	Apollo Part Task Trainer	15
6	Visual Cue Attachments	36
7	Scanning Telescope Image Generator	38
8	Sextant Image Generator	42
9	Boost Trajectory Coordinates	50
10	Orbital Injection Coordinates	60
11	Spacecraft Attitude	64
12	Entry Path	67
13	Entry Display	73
14	Vehicle Dynamics and Guidance Simulation Block Diagram	74
15	Orbital Coordinate System	76
16	Digital and Analog Equipment Block Diagram	82
17	Trainer Command Module: Elevation	88
18	Trainer Command Module: Top View	89
19	Guidance and Navigation Display: Lower Equipment Bay	95
20	Communications Block Diagram	97
B-1	Stabilization and Control System Block Diagram	B-5
B-2	Guidance and Navigation System Block Diagram	B-11
B-3	Propulsion System Block Diagram	B-19
B-4	Communications and Instrumentation System Block Diagram	B-25
B-5	Environmental Control System Block Diagram	B-31
B-6	Electrical Power System Block Diagram	B-37
B-7	Launch Escape System Block Diagram	B-45
B-8	Earth Landing System Block Diagram	B-51
B-9	In-Flight Test System Block Diagram	B-57
B-10	Geometry of Earth Orbit	B-63
B-11	Total Coverage of SCT at 25° Offset Search Mode Position	B-63
B-12	View on Surface for Trunnion Axis Freedom	B-64
B-13	Optics Coverage	B-67
B-14	Landmark and Star Juxtaposition	B-69
B-15	Coarse Alignment	B-74
B-16	Fine Alignment	B-74

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TABLES

Table		Page
1	Training Related to Visual Cues	33
2	Definition of Symbols	51
3	Digital Computer Instructions and Data Estimate	83
4	Analog Equipment Required for Mechanization of Problem Load	86
A-1	Instructor and Training-Time Requirements	A-2
C-1	Functional System Integration	C-3

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INTRODUCTION

The philosophy and general requirements for an Apollo Part Task Trainer are set forth in this document. The primary purpose of the Part Task Trainer is to make available the means for the Apollo crew to practice operational procedures which include manual tasks. The design of the Part Task Trainer is intended to include the simulation of the Apollo spacecraft with sufficient realism to permit the crew to train in the several task requirements during actual missions.

The Apollo program does not lend itself to in-flight training, consequently, extensive training must be accomplished prior to actual flight. Categorically, the Part Task Trainer is designed to provide procedures training as associated with the crew integrated tasks in spacecraft management.

Expected modifications of actual equipment will affect training equipment. The Part Task Trainer design requirements reflect the need for up-dating the trainer equipment, to provide the proper training environment. The trainer will be of exceptional value where considerable repetitive training exercises are required. Features of adaptability designed in the Part Task Trainer to meet with changing task requirements permit the training of an individual crew member, as well as integrated crew training.

Selected mission segmented training procedures incorporated in the Part Task Trainer will have an associated and realistic malfunction insertion program, typical of the type of malfunctions which would be experienced in the actual spacecraft. Associated evaluation of crew response to malfunctions will be provided by the computing equipment and the instructor-operator personnel.

Automatic evaluation equipment is not specified in this report. The computer complex will be designed so that expansion can include automatic evaluation equipment if required. To permit real time evaluation two 8-channel recorders, as well as any special additional instrumentation that may be required for evaluation of the task, will be supplied. The trainer will have the flexibility to select and re-select mission segment procedures training problems at the option of the instructor-operator personnel.

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The Part Task Trainer will require at least one instructor and one computer program operator. Additional instructors are required depending on the objective of the training session. Instructor requirements based on the number of crew members and the tasks being practiced are indicated in Appendix A. These requirements are based on normal task situations. Problem situations concerning operations, navigation, and system malfunctions will require at most three instructors and one computer program operator.

Primary control of the trainer will be exercised at the instructors' station, with associated computer program control being directed by the instructor-operator station. The over-all operation and training program implementation will be under the direction of the control station equivalent position at the instructors' station.

Visual simulation equipment will be included in the Part Task Trainer to allow the crew to proceed with task training required for management of the Apollo spacecraft. Primarily, visual simulation will consist of equipment necessary for Navigation Task Training. Certain other selected tasks will be included, depending upon cost and task requirements.

Aural simulation equipment will be included to re-create the spacecraft noise level environment, and interrupt noise events. Aural cue simulation due to crew action will provide a realistic environmental man-machine association. Human engineering studies currently being developed in the actual Apollo spacecraft will be utilized to provide identification of required training for the crew in the Part Task Trainer.

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I. TRAINER TASK REQUIREMENTS

The Apollo Part Task Trainer will provide a means to accomplish procedures training objectives. Particular crew tasks associated with Apollo missions will require extensive simulation exercise for crew survival and mission success. The Apollo Part Task Trainer will also provide training for the Apollo crew in the development of spacecraft flight procedures and management to develop the manual skills of the crew.

The Apollo Part Task Trainer will provide spacecraft management procedures training in the tasks associated with the following mission phases:

- | | |
|-----------------|---------------|
| (1) Launch | (3) Midcourse |
| (2) Earth Orbit | (4) Reentry |

This procedures training will be directed toward familiarization and integration of the spacecraft crew control actions with the Apollo systems, displays, and controls. The Apollo Part Task Trainer will provide a means for the crew to perform the operational sequences required for the actual spacecraft task exercises and management.

The Part Task Trainer will provide real-time simulation of selected sections of the total mission. In addition, procedures training will be provided in the launch and reentry phases. Task and procedures training will be provided also over small, selected segments of the earth-orbit and mid-course phases.

TRAINER EQUIPMENT AND SYSTEMS

The Part Task Trainer is composed of major equipment sections with associated tie-in equipment to provide a complete training complex. The major equipment sections will include:

1. Command Module
2. Digital Computer
3. Analog Computer

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4. Instructors' Console
5. Associated Support equipment
6. Major Subsystems

These equipments will be associated to produce a simulation training facility as depicted in Figure 1. Associated with the major equipment sections will be systems and subsystems simulation equipment, which will be developed to properly simulate the spacecraft systems and subsystems, as well as the associated support equipment unique to the Part Task Trainer. These equipment groups will provide the capability for trainer operation and problem control. Figure 2 is a block diagram of the trainer complex.

Command Module

The Command Module will contain control and display panels similar to those in the Apollo spacecraft. The displays in the Command Module will be controlled by the computing equipment; however, associated control and particular override controls will be provided at the instructors' console.

Displays associated with tasks involving a high degree of manual skill shall be perceptually identical in accuracies and response to those in the actual spacecraft. Inactive displays are those under the complete manual control of the instructor, and they will have identical scale ranges and appearance as those of the Apollo spacecraft.

With reference to Figure 3, active controls and inactive controls will be designated according to their pertinent function within the mission segment selected for procedures training simulation.

From the Command Module, the crew will actively control the simulated spacecraft provided by the computer simulation equipment.

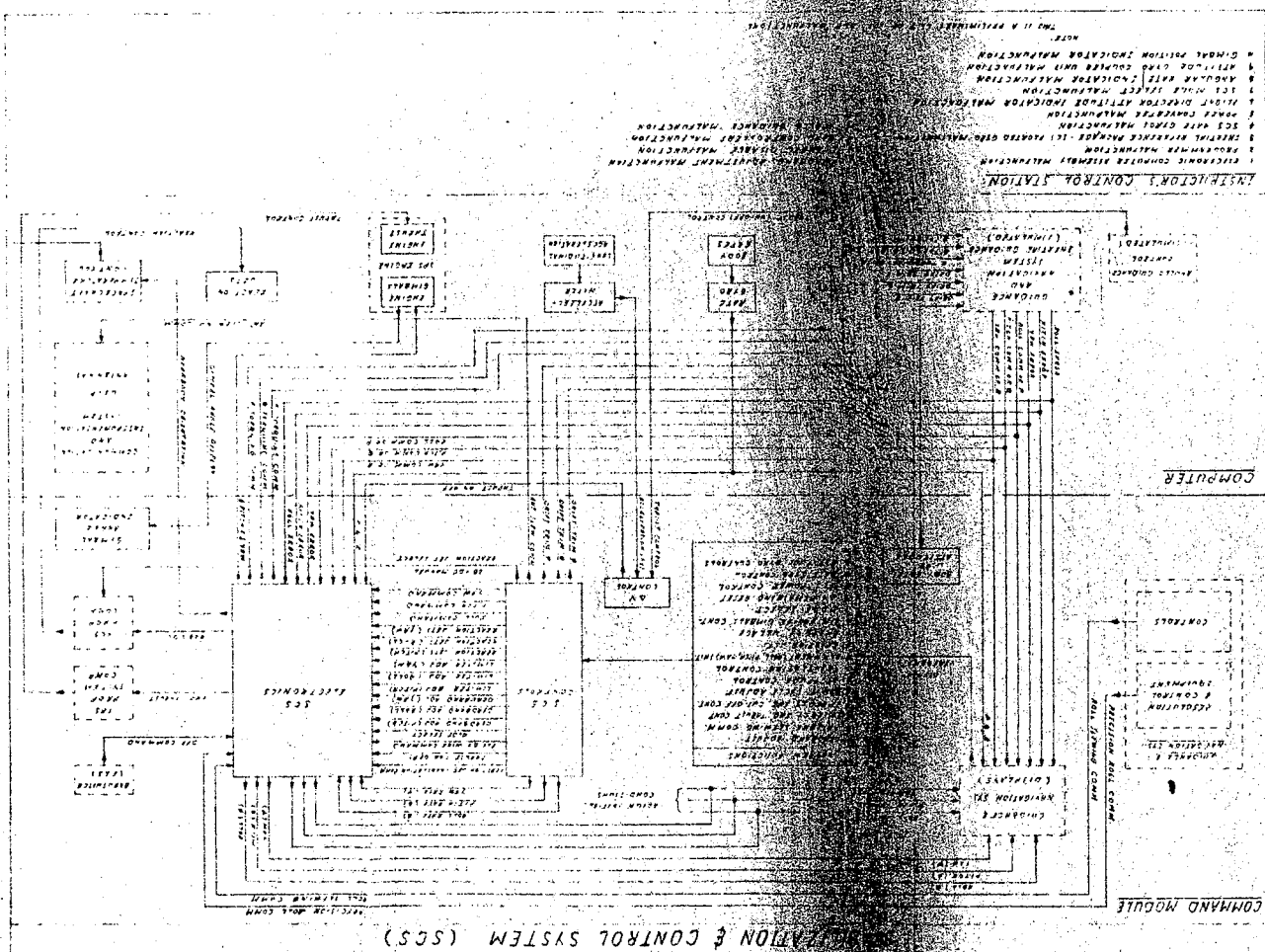
Digital Computing Equipment

Digital computing equipment is provided to perform the necessary control and iterative computing operations to provide a real-time simulation of selected segments of the Apollo mission. The primary functions will include:

1. Execute Training Programs
2. Control Analog Computer
3. Generate Training Data and Displays

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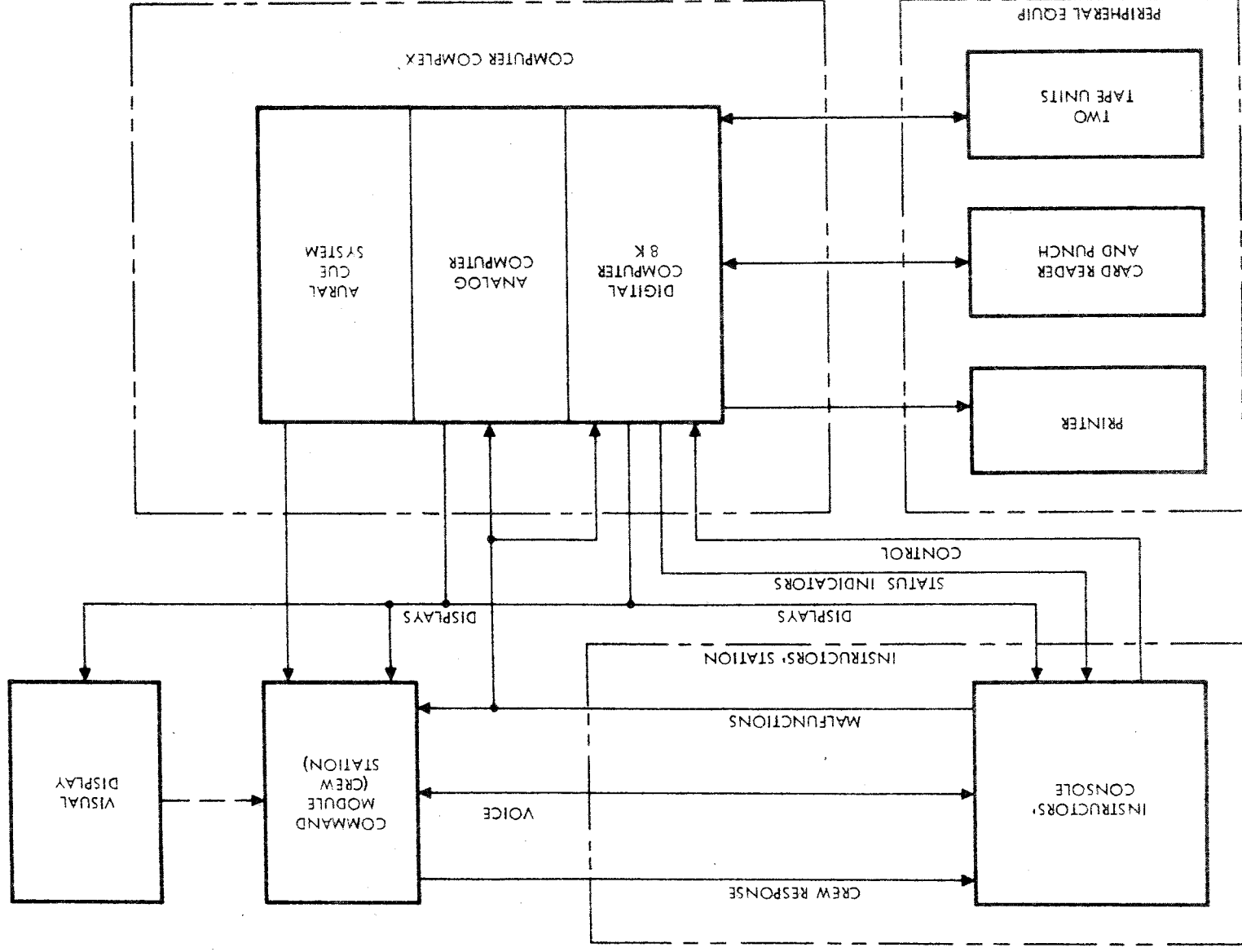
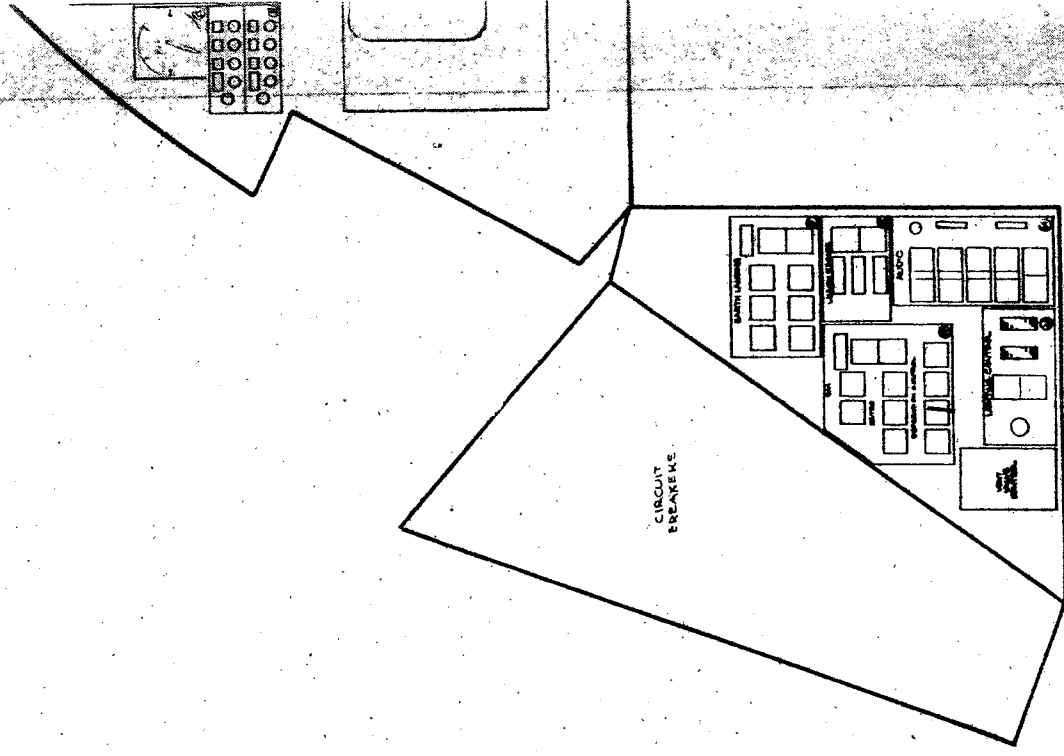


Figure 2. Trainer Complex Block Diagram

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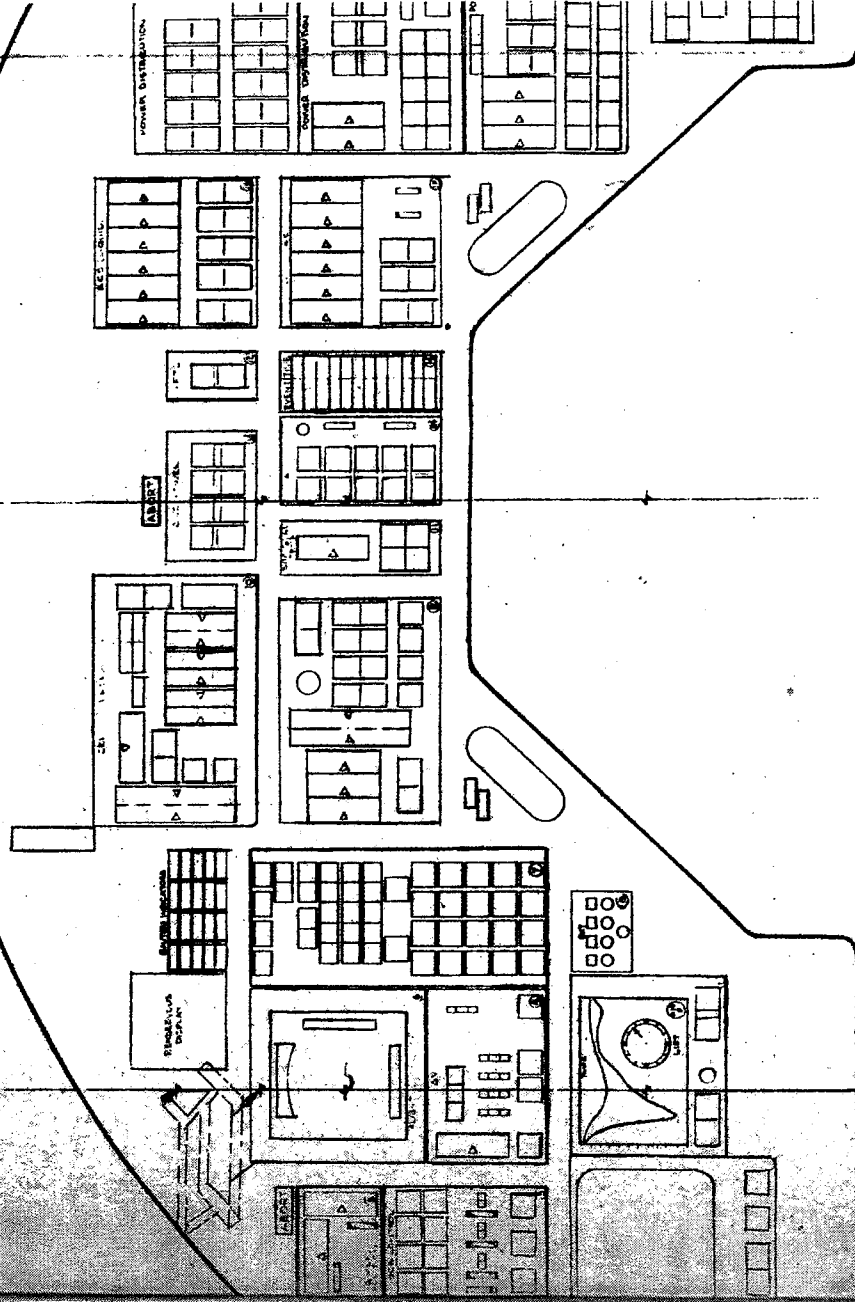
FOLDOUT FRAME /

NORTH AM

CENTER POSITION
E 000

CONTROL POSITION
E 240

BY 1



FOLDOUT FRAME 2

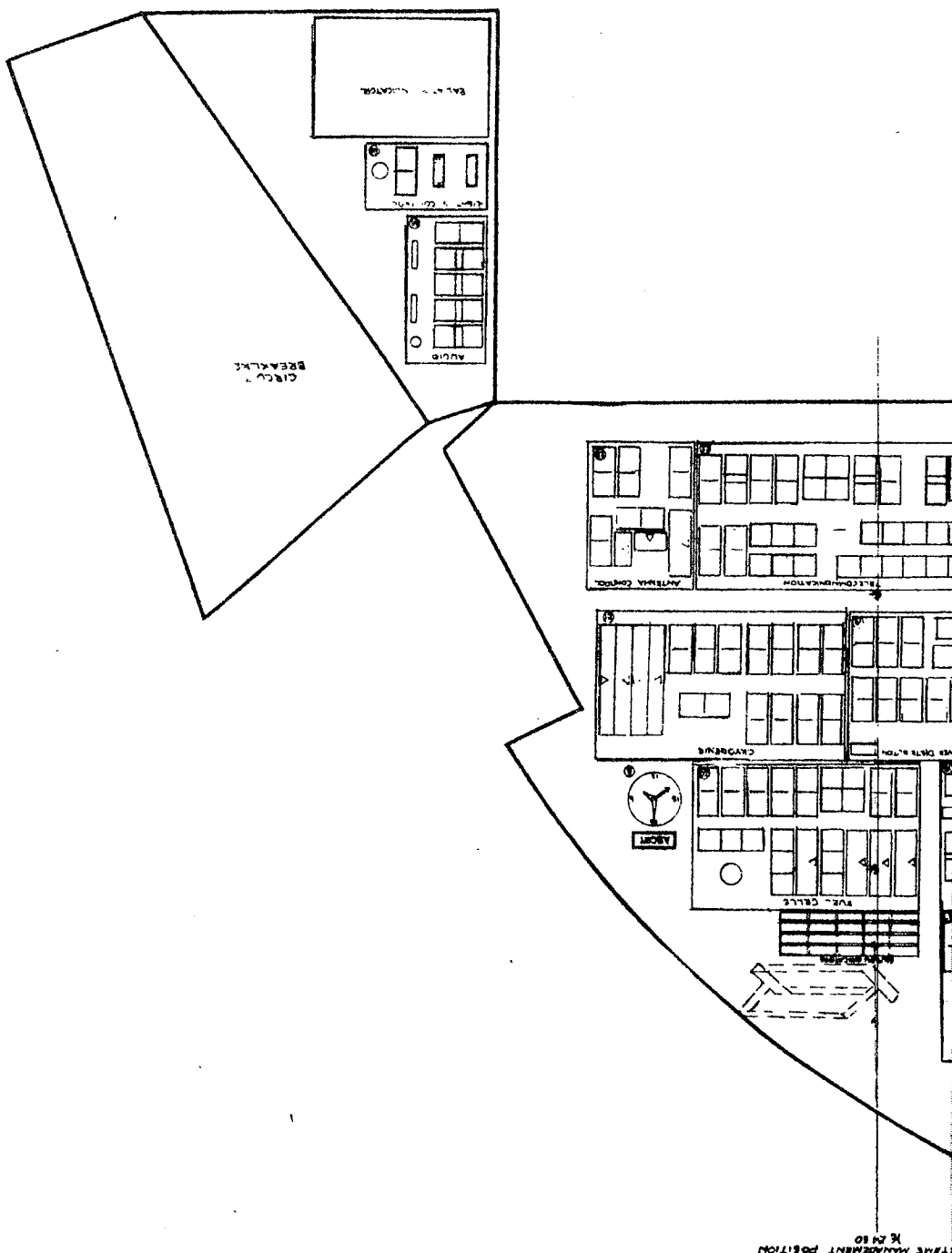


Figure 3. Design Layout: Display Panels Arrangement

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Analog Computing Equipment

Analog computing equipment will be provided for the simulation of the rotational characteristics of the spacecraft. In addition, analog equipment will be required for support equipment unique to the trainer required program selection and control. The primary functions will include:

1. Attitude Control
2. Reentry Simulation
3. Analog Displays

Instructor Console

The instructors' console will provide the instructor-operator control of training problem implementation. The instructor-operators will be required to provide the following:

1. Introduce into the trainer complex the required training program initial conditions.
2. Monitor, advise, instruct, and create conditions with regard to training schedules.
3. Alter training programs to provide re-training or extended training for the crew.
4. Recognize problem areas in procedures training, and provide information for re-programming of training schedules.

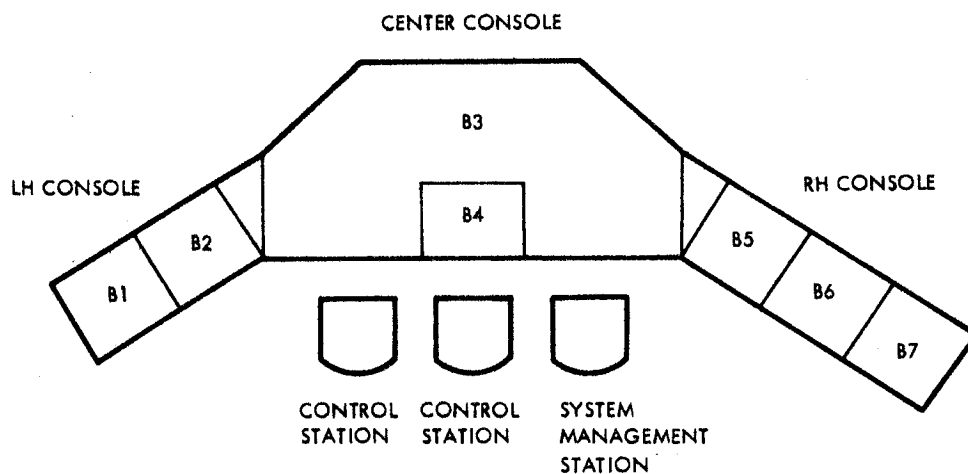
With a reference to Figure 4, the instructors' console will provide the instructor-operators with necessary associative support equipment to implement training schedules on the Apollo Part Task Trainer.

Associated Support Equipment

The associated support equipment for the hybrid computer employed for the Part Task Trainer includes:

1. Digital computer programming and support equipment
2. Instructors' console problem set-up and control equipment

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B1 - INSTRUCTORS' CONSOLE MASTER CONTROL & C/O PANELS

B2 - SET UP CONTROLS & C/M L.H. CONSOLE REPEATER INSTRUMENTS

CENTER CONSOLE

B3 - MAIN CONTROL PANEL (C/M) REPEATER INSTRUMENTS

B4 - MALFUNCTION CONTROL PANEL

R.H. CONSOLE

B5 - C/M R.H. CONSOLE REPEATER INSTRUMENTS & CIRCUIT BREAKERS

B6 - LOWER EQUIPMENT BAY (C/M) GUIDANCE & NAVIGATION

B7 REPEATER INSTRUMENTS

Figure 4. Instructors' Console

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3. Command Module crew controlled support equipment
4. Power supply and power conversion equipment

This equipment will be identified concurrent with design definition.

Major Subsystems

Major subsystems to be employed as an integral part of the Part Task Trainer include:

1. Visual cue simulation equipment
2. Aural cue simulation equipment
3. Trainer communication system*

These subsystems will be associated physically with the other trainer equipment sections. The visual cue system will provide a visual simulation of the sextant and telescope. The aural cue system will provide sound effects due to rocket engines, reaction jets, and other discernible noises. The communication system will provide for voice transmission between instructor-operator stations and crew stations. A perspective drawing of the trainer complex is presented in Figure 5.

RELIABILITY

To assure attainment of reliability requirements for the Apollo Part Task Trainer, considerations, studies, and design principles as outlined below shall be undertaken.

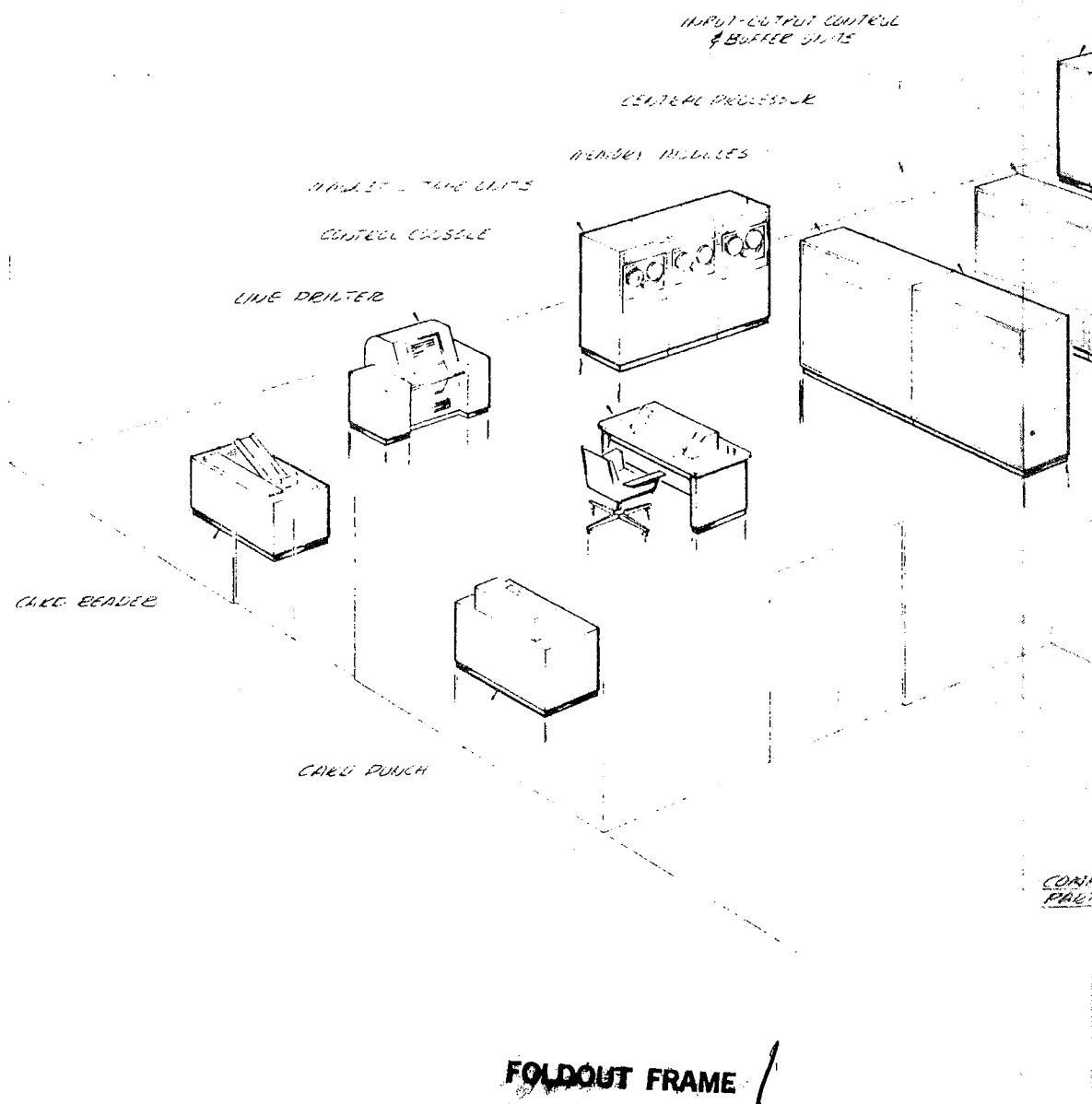
Reliability Program Considerations

A reliability program for the Part Task Trainer shall be utilized that recognizes the concept of inherent reliability of design, i.e., that reliability is limited by the design, and that effort must be concentrated early in the design phase. Emphasis and effort shall be placed on those activities necessary to assure retention of reliability during manufacturing, development testing, and operational demonstration and use phases. Where demonstration of reliability is specifically stated, such statements shall include an accompanying statement of the confidence level to which the reliability will be demonstrated.

*This equipment will be GFE.

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ALACU EQUIP

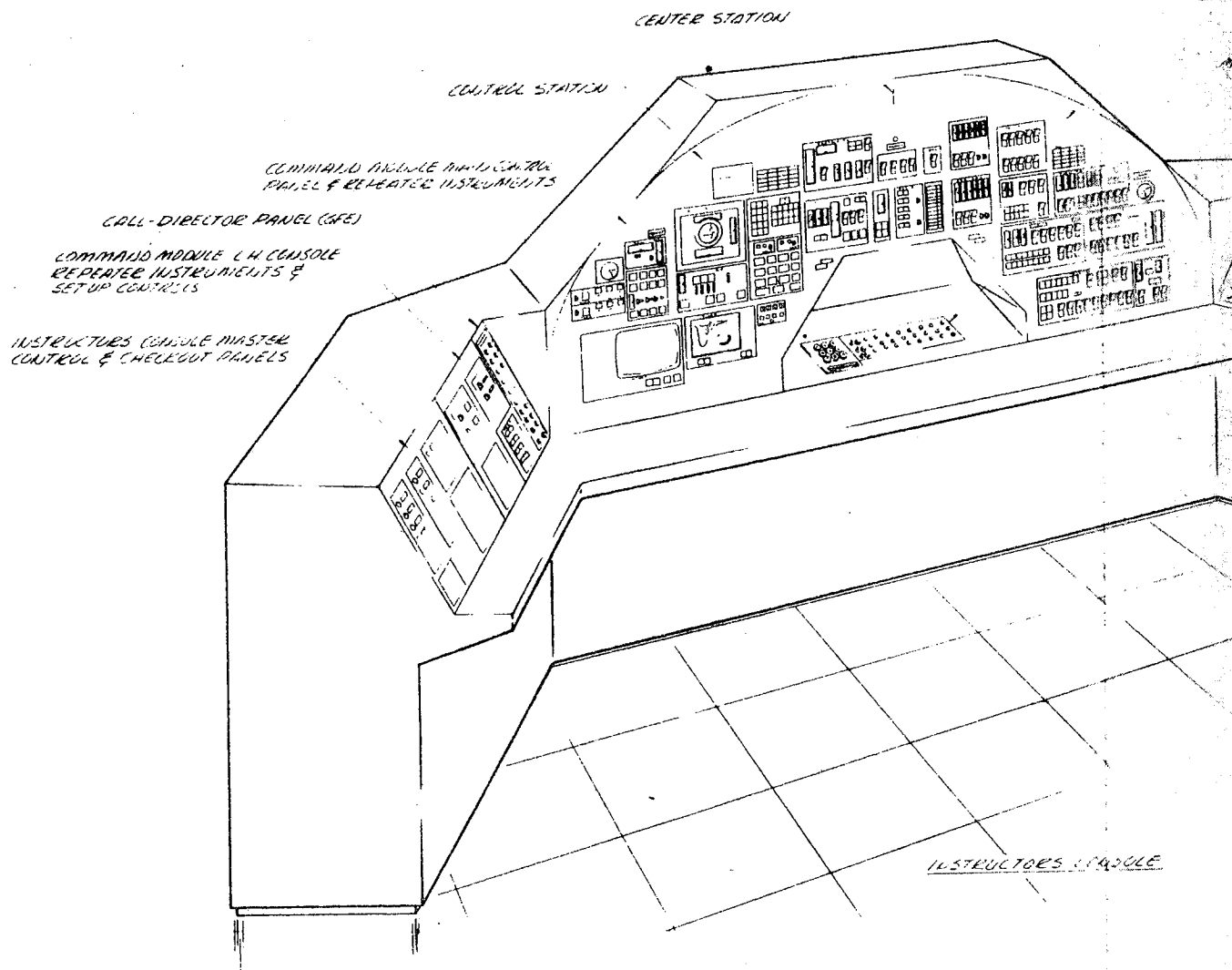
ALACU EQUIP

ANALOG TAPE RECORDER

DC POWER SUPPLY

INTER COMPLEX
TAPES TRAILER

FOLDOUT FRAME 2



FOLDOUT FRAME 3

TRANS MANAGEMENT STATION

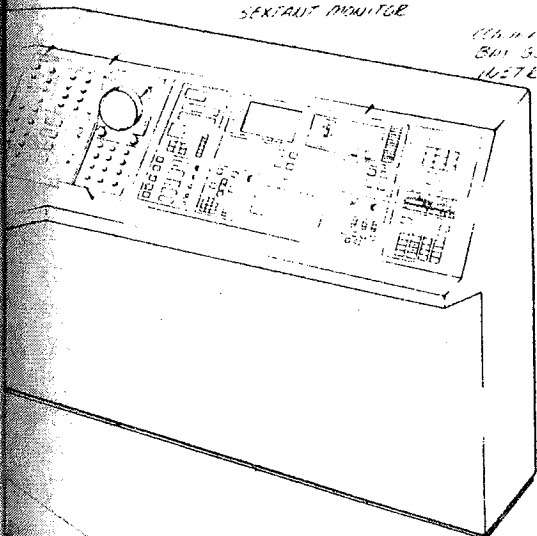
DEFENSE CONTROL PANEL

CALL DIRECTOR PANEL SEE

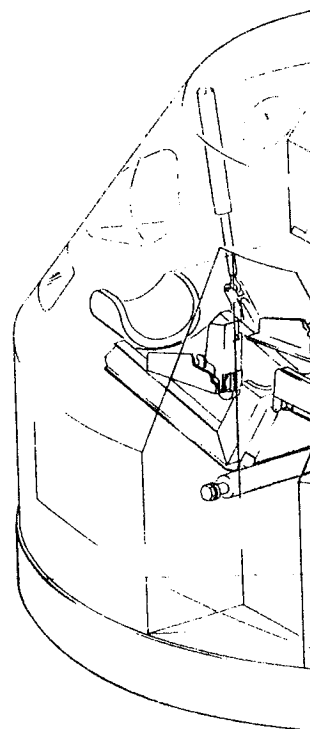
COMBAT LINE MOUNTED IN CONSOLE
RECEIVER INSTRUCTIONS & CIRCULAR
SERVICES

SEXTANT MONITOR

COMBAT LINE MOUNTED IN CONSOLE
BUT 30. MILES & NAVIGATION RESEARCH
INSTRUMENTS

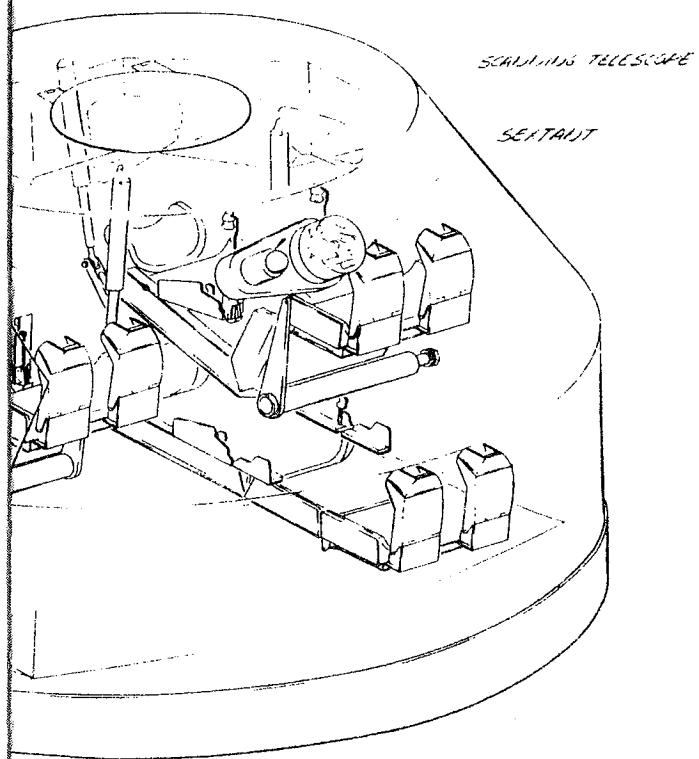


COMBAT & NAVIGATION RESEARCH
CONTROL PANEL

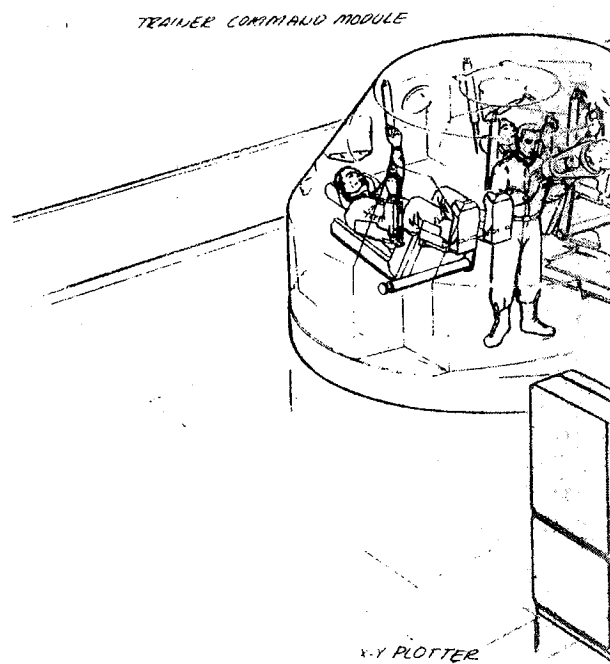


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4

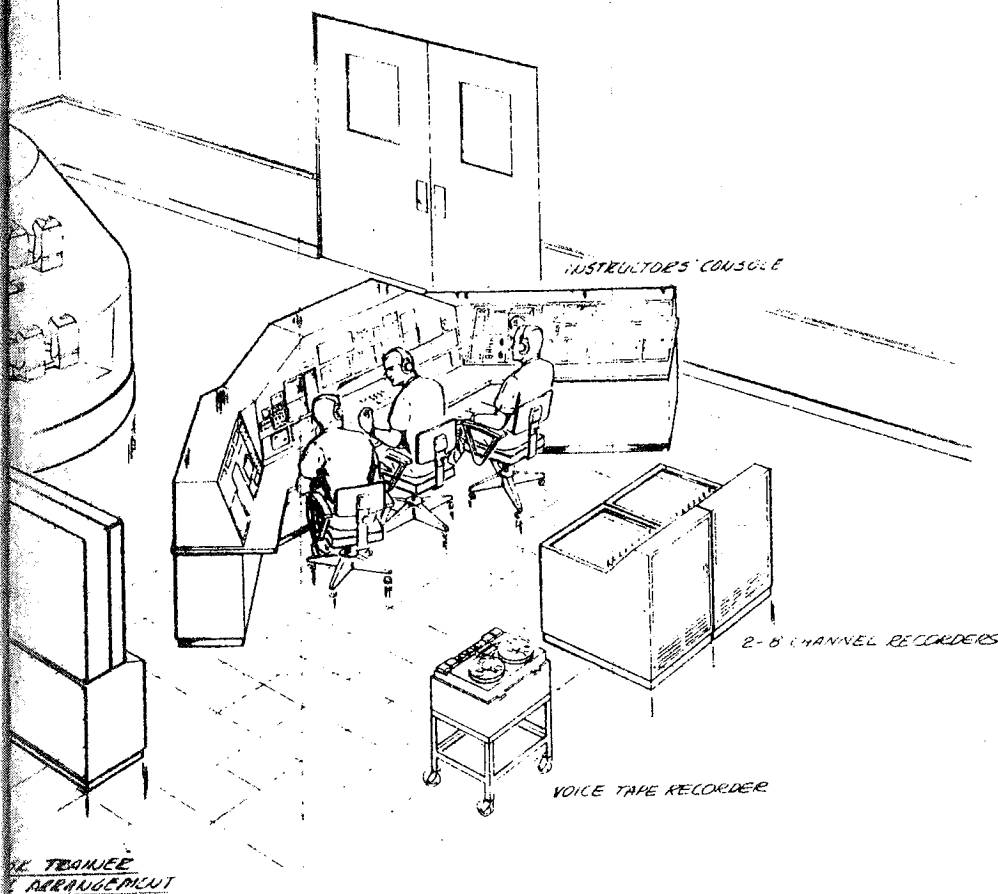


TRAINER COMMAND MODULE



PART 7A
OPERATIONAL

FOLDOUT FRAME 5



1. COMPUTER OFF LINE EQUIPMENT NOT SHOWN
NOTE: UNLESS OTHERWISE SPECIFIED

FOLDOUT FRAME 6

Figure 5. Apollo Part Task Trainer

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Reliability Requirement Studies

Preliminary and continuing studies to validate specific requirements shall be undertaken and form the basis for revising the quantitative reliability requirements for the Part Task Trainer Subsystems, assemblies, and parts. Apportionment of reliability shall be accomplished by analyzing the importance (effect of failure) of the trainer elements, complexities and functions including alternate modes of operation. Progressive reliability goals shall be established for each major phase of the Development Program and review points shall be specified. The detailed approach used in defining requirements and establishing feasibility shall be appropriately covered in the program description and subsequent periodic reports.

Reliability Design Principles

Reliability design principles shall include provisions to assure that reliability principles are considered in the design. Some examples are as follows:

1. Failure analysis concerning mode, probable cause, and effect of failure
2. Standardization of design and parts
3. Simplification of design
4. Assessment of state-of-the-art
5. Trade-offs of parameters
6. Derating of parts
7. Redundancy for greater reliability
8. Maintainability
9. Producibility
10. Ease of operation
11. Ease of transportation
12. Ease of inspection
13. Safety margins

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- 14. Human engineering
- 15. Operational environment
- 16. Calibration

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II. TRAINER CAPABILITIES

In this section the training capabilities of the Apollo Part Task Trainer will be discussed.

ABORT SIMULATION

During the prelaunch countdown, two types of abort can occur: (1) an abort that requires firing of the launch escape tower engine and (2) an abort that simply requires shutdown. Both can be simulated in the Apollo Part Task Trainer. The first type of abort will be simulated up to the time at which the drogue chute is deployed. The displays presented to the crew during this maneuver will be relatively simple, and will emphasize event sequences more than the dynamics of the situation.

Several kinds of aborts can occur from lift-off to orbital insertion. These aborts can be classified in several ways, e.g., atmospheric and post-atmospheric. For all practical purposes, a post-atmospheric abort is defined to be one which occurs after escape tower jettison. Such aborts will be made in the spacecraft using the Service Module engine; the Command Module and Service Module remain together during the early part of this type of abort. The abort simulation will require that the Command Module and Service Module be separated and the Command Module be aligned for reentry. The trainer will provide a continuous and realistic simulation of the event sequence from the abort through alignment for reentry. The switch-over to reentry mode can be made at this time, and a continuous simulation made through drogue chute deployment.

Atmospheric aborts under this classification will involve use of the escape tower. These aborts differ widely insofar as aerodynamics is concerned, but for the purposes of trainer simulation they can be grouped together. The sequence of events that occurs after such an abort has been initiated will be simulated. The abort trajectory data will be preprogrammed into the computer.

During reentry, abort conditions which require a switch-over to the manual reentry guidance mode will be simulated. The dynamics of the manual control will be simulated to the extent required to give the crewmember a true representation for the effect of his control operations.

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SPECIAL FAILURES

Reentry (Manual Mode)

During the reentry section of the mission, the crew will be primarily concerned as to whether or not the manual reentry guidance mode should be selected. Because of this, emphasis will be given for simulating malfunctions in the stabilization and control system and the guidance and navigation system.

Malfunctions in the G&N and SCS systems can be quite critical during entry. Considerable experience (i.e., training) will be required to enable the crew members to quickly detect critical malfunctions in these systems. The training can best be accomplished through a faithful simulation of the entry phase of the mission. With this simulation capability built into the trainer, it will be possible to initiate varied malfunctions and duplicate the corresponding indications that would occur in flight. A complete and sufficiently accurate simulation of this mission phase will allow inserted malfunctions to propagate naturally and produce the required indications.

SIMULATED MALFUNCTIONS

A limited capability will be provided to malfunction all systems applicable to the Apollo Part Task Trainer. These systems are:

1. Stabilization and Control
2. Guidance and Navigation
3. Propulsion
4. Communication
5. Environmental Control
6. Electrical Power
7. Launch Escape
8. Earth Landing

It is not physically possible to introduce all conceivable malfunction and failure conditions and combinations thereof as such could occur at any point in the Apollo mission. In spite of this, training must be provided to assure the development of the crew's ability to successfully recognize, correct, or otherwise overcome and/or nullify the effects of all malfunctioning where such action is possible.

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Simulated failure situations will be determined from a criteria based upon the characteristics of integrated systems and the crew's ability to cope with these situations which have varying degrees of task difficulty.

Criteria for the selection of specific malfunctions for use in training are as follows:

1. Criticality in terms of mission success
2. Probability of occurrence during an actual mission on the basis of systems reliability
3. Applicability to general training requirements

Malfunctions inserted into the Stabilization and Control System will be allowed to propagate throughout the system. Since this system will be simulated with a high degree of realism, complex failure situations can be presented and studied for crew training purposes.

Malfunctions inserted into the Guidance and Navigation System do not propagate through the system. Their effects result only in an out-of-tolerance error indication which will have been predetermined and will be presented according to a rigid plan.

Failure situations will provide the crew with practice in the following tasks:

1. Detecting malfunctions
2. Isolating and correcting malfunctions (limited)
3. Reporting the occurrence of a malfunction and its effect upon the various systems
4. Performing emergency procedures
5. Performing abort procedures

Malfunction Insertion

All simulated malfunctions will be initiated by the instructor. When more than one instructor is present, only one will control the insertion of malfunctions. Notification will be given to the other instructors, if required, either through a warning signal on the instructors' console or via the intercom, that the malfunction has been introduced.

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Displays affected will respond immediately after the insertion of a malfunction. Where precise timing is required, the malfunction will be preprogrammed and automatically inserted.

The instructor will insert malfunctions by using simple push button, toggle switch, and rotating knob type controls as well as computer punchcards.

Display Functions

Displays will be capable of indicating abnormal or out-of-tolerance conditions as controlled by the instructor.

When required for training purposes, two or more displays will be simultaneously activated as required by the affect of the malfunction on various systems.

Detection, Isolation, and Correction

The crew will detect simulated malfunctions by observing simple or complex indications as displayed by:

1. ON-OFF "CAUTION" and "WARNING" lamps.
2. Instrument pointer positions and movements.
3. Aural sounds.

A study shall be undertaken to determine which displays should be used for indicating malfunctions. This will depend upon the type of malfunctions selected and their affect upon the various displays.

Troubleshooting procedures concerned with isolating malfunctions will be kept to a minimum.

Malfunctions will be corrected by performing simple adjustment, alignment, and switching tasks.

In-flight maintenance pertaining to remove-replace tasks will not be performed.

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Evaluation Equipment

While extensive training evaluation will not be performed, the following recording equipment will be provided, to permit instructor monitoring and post-training evaluation:

Two eight-channel recorders or their equivalent will be provided with a selection of at least 50 variables during any one exercise and a total of 75 inputs.

An X-Y plotting board will be provided to permit real (trainer) time display.

A portable audio tape recorder will be provided to permit recording of crew and instructor conversation for subsequent evaluation. In addition a playback deck will be provided to permit the use of pre-recorded audio cues.

Crew Monitoring

The instructor will be capable of monitoring all crew stations display indications and control positions. This will be accomplished by repeater and special instrumentation at the Instructors' Console and will be located in the same relative position as in the actual crew station. Crew station control position will be indicated by displays at the Instructors' Console.

Malfunction Control

The instructor will have control of overriding and terminating inserted malfunctions.

Malfunctions which generate gradual affects shall be controlled automatically.

INITIALIZATION OF THE TRAINING PROBLEM

Initialization is defined to include loading of the program into the digital computer, setting up the patch boards on the analog computer, and setting up of all manually controlled displays in the Command Module. It is estimated that about 10-15 minutes will be required for this process when going from one major phase to another (atmospheric to extra-atmospheric or vice-versa); and that less than 5 minutes will be required to restart within a major phase. In the latter case most of the restart time will be needed to reset manual controls. The time required to repeat the same training mission will also be mainly dependent on that needed to reset manual controls.

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Initialization is best considered separately for the atmospheric (launch and entry) and extra-atmospheric (earth orbit and mid-course) mission phases. This results because of the great difference in the dynamics of these phases and because of the different training philosophy for the two phases. In the atmospheric phase the training missions will be continuous, while in the extra-atmospheric phases they will consist of short time segments distributed over the entire mission phase.

Atmospheric Phase Initialization

The training mission for the launch phase begins at T-20 and ends at orbit injection. Initial conditions required for the digital computer may be inserted at any point during the interval from T-20 to T-0. No initial conditions for the computer will be required during the interval between T-0 and orbit injection. Since the trajectory data for powered flight must be entered into the computer prior to the run, it will not be possible to initiate arbitrary abort conditions during the run; these must be predetermined and pre-programmed into the computer. This statement applies to aborts dictated by trajectory considerations. Aborts dictated by other causes (e.g., ECS failure) can be initiated at any time.

The training mission for the entry phase begins between an altitude of 600 K feet and 400 K feet. This applies to the normal entry training mission. When entry must be performed from a launch abort, this limitation does not exist because initial conditions will be automatically set up by the launch phase computer program. The inherent complexity of the entry dynamics makes it impractical to attempt to set up initial conditions at arbitrary altitudes.

Extra-Atmospheric Phase Initialization

As noted earlier, training missions for these phases consist of short time segments distributed over the entire phase concerned. There are no limitations as to when the training mission can begin. Only attitude dynamics will be simulated; the set-up of problems are of minor importance. Most of the set-up time will be needed for the manual setting of controls and indicators.

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MAINTENANCE AND CHECKOUT

Three types of automatic checkout will be provided to detect malfunctions in the trainer complex:

1. Simple tests during system operation.
2. Readiness test before beginning operation.
3. General diagnostic program.

During system operation, simple tests such as built in computer self checks, checks for parity, and overflow will be performed. Short problems will also be solved as checks on computer operation. These will also test the input-output and linkage systems. Major system malfunctions during a run should be detected by these tests. The subroutine required to perform these tests would be part of the operational programs and will be performed on a low priority basis. The readiness test will be performed before running a sequence of training missions, (once a day). This test will include a digital computer self-check, a check of analog computer operation, a check of the linkage system, and a check of displays in the Command Module and Instructors' Station that are under direct computer complex control. The general diagnostic program will be run as required, and will be a more sophisticated version of the readiness test. This program will contain subroutines that will be used to isolate malfunctions to a black box level in the trainer complex. Such subroutines will be used only if a malfunction is indicated during the checkout. The automatic checkout provided will utilize the digital computer to the fullest extent possible in order to provide rapid and efficient means of checking out and maintaining the trainer complex.

In addition to automatic checkout, checklists and manuals will be provided to facilitate manual checkout and maintenance. During problem set-up many displays must be set to the desired nominal reading; this operation is in part a system check. Readily accessible test points will be provided as an aid to manual troubleshooting. The operation of all major trainer systems can be observed at these test points.

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III. SUBSYSTEM SIMULATION

The simulation requirements for the trainer subsystems are described below. The actual system descriptions with their associated displays and controls are included in Appendix B.

STABILIZATION AND CONTROL SYSTEM

Systems components which will be simulated by the computer are: attitude gyro coupler unit, orbit rate resolver, inertial reference package, rate gyro package, deadband generator discrete ranges, reaction jet selection logic, accelerometers, limiters, and the switching and summing involved in different modes of operation. The attitude rates, translations, and velocity changes produced by the firing of the reaction jets or main engines will be simulated.

All displays and controls normally available to crew members in the actual spacecraft will be provided in the trainer and will provide realistic control over simulated spacecraft motion with concurrent display of applicable parameters sufficient for crew control execution.

GUIDANCE AND NAVIGATION SYSTEM

Orbital and Midcourse Phases

Training will be provided in the following major part tasks:

1. IMU alignment
2. Optical equipment operation
3. Velocity corrections procedures

This training will provide familiarization with the procedures and practice in the manual skills associated with these tasks. In particular, the purpose of this training is to instruct the crew in the use of the navigation equipment, e.g., sextant, scanning telescope, AGC keyboard, and other controls and displays.

The optical readings obtained by the crew will be used to evaluate their performance in the use of the navigation and guidance equipment; these readings will have no effect on the trajectory calculations. In order to

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assess the performance of the crew in the use of the optical equipment, a high degree of repeatability will be required. The visual cue system, in conjunction with the simulated sextant and telescope, will provide the required degree of repeatability.

The guidance and navigation system functions will be simulated to the degree required to provide the training described above. The Apollo guidance computer will be simulated by the trainer computer complex only to the extent of supplying realistic displays. The scanning telescope, sextant, IMU alignment panel and inertial platform control panel will be controlled by the trainer computer complex.

Launch and Reentry Phases

The navigation station displays and controls (those under computer complex control) will not be functional during the launch and reentry mission phases. However, certain displays on the main control panel (e.g., computer display panel, FDAI panel, and reentry display) will be controlled by the trainer computer complex. The guidance and navigation system will be functionally simulated to the extent required to control these displays in a realistic manner. During reentry (in the automatic guidance mode), the MIT guidance scheme will be simulated. The trainer digital computer will provide a functional simulation of the Apollo guidance computer, insofar as the solution of the MIT guidance equations is concerned. Scaling and solution rates will be similar to that of the AGC.

PROPULSION SYSTEMS

Throughout the various Apollo missions, the crew is required to manage the spacecraft propulsion systems. These systems are:

1. Service propulsion system (SPS)
2. Reaction control system - Service Module (RCS-S/M)
3. Reaction control system - Command Module (RCS-C/M)

and they are monitored and controlled through the SPS panel and the RCS panel.

For this trainer, no attempt will be made to mechanize the mathematical relationships describing temperature, pressure, and flow, in order to conserve computational equipment. These displays will be static in nature and will be adjusted by the instructor to normal or off normal readings, at his option, prior to the training mission. Instead, procedures for proper

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system operation and fuel management will be emphasized. The valving and control circuits will be simulated to a limited degree and such functions as fuel consumption, gimbal angle readout, and thrust transient characteristics will be reproduced in sufficient detail to provide realism.

COMMUNICATIONS AND DATA SYSTEM

The following spacecraft display and control panels will be provided in a realistic and operable condition:

1. Timing Displays - All timing devices present in the actual spacecraft will be provided in operating condition. Digital timing devices will be supplied with a timing pulse from the computer complex. Other timing devices will be mechanical. All timing devices will be manually settable consistent with the actual spacecraft equipment. Coordination for setting crew station clocks and duplicate instructors' station clocks will be accomplished, as necessary, by voice communication.
2. Antenna Control Panel - All indicators and controls will be operable. The antenna subsystem will be simulated to the extent necessary to provide realistic crew control of antenna position and concurrent feedback (noise level) into the communications channels. Task analysis will determine whether manual (i.e., instructor) or computer control will be required.
3. Telecommunications Panel - Indicators and controls will be provided in an operable condition but will not indicate or control the status of actual or simulated telecommunications equipment. (Exceptions to this exist where controls involve status and mode of operation of voice channels.)
4. Audio Control Panel - Controls will be provided in operating condition such that individual crew member mode selection and control may be exercised over the simulated communications system.

In addition, control functions associated with the communications systems will be indicated on the instructors' console. A capability will exist for controlling audio quality reception of the three crew members separately even though each may be talking at the same time.

All functions of the ground operational support system (GOSS) will be simulated and will be under the control of the instructor(s).

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ENVIRONMENTAL CONTROL SYSTEM

The following spacecraft display panels will be provided in a realistic and operable condition:

1. ECS (liquid) display panel
2. ECS (gas) display panel
3. Cryogenic display panel

Most displays will be manually controlled by the instructor. Displays monitored by the crew will indicate simulated environmental conditions of an actual mission. The crew controls will affect applicable displays but will not control existing environment within the trainer cabin. A pressure suit air supply connection will be provided within the Command Module for use with pressurized suits which are GFE. The waste management panel is non-functional and will therefore be realistically mocked up.

ELECTRICAL POWER SYSTEM

The following spacecraft display panels will be provided in a realistic and operable condition:

1. Power distribution display panel No. 1
2. Power distribution display panel No. 2
3. Power distribution display panel No. 3
4. Fuel cells display panel

No attempt will be made to faithfully provide a simulated electrical power system. Most displays will be manually controlled by the instructor. All crew operable controls will interface with the instructors' station and will cause appropriate information to be displayed on the panels consistent with actual system operation.

Electrical system malfunctions inserted into the simulated system by the instructor will energize the affected meters and indicators to indicate the malfunction. Correction of the malfunction by switching to alternate system or systems shall demonstrate corrected indications as in the operational system.

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LAUNCH ESCAPE SYSTEM

The controls and displays of the launch escape system that will be simulated are composed of the following:

1. Displays
 - a. Abort sequence ready
 - b. Abort sequence initiate operation
 - c. LES tower jettison sequence completion
 - d. LES tower mechanism release completion
2. Controls
 - a. Abort sequence arm command
 - b. Abort sequence initiate command
 - c. Tower jettison sequence initiate command
 - d. Launch escape motor fire command

The operation of the simulated launch escape system will be controlled by the computer with crew command override. Computer subroutines will be provided for the instructor to permit variation in the exercise of the launch escape system. The controls and displays will be identical to those in the spacecraft and the displays will be actuated by the computer.

EARTH LANDING SYSTEM

Computer complex control will be exercised over applicable earth landing functions and procedures. Controls and displays which will be provided in a realistic and operable condition are as follows:

1. Displays (event indicator)
 - a. Earth landing sequence ready
 - b. Forward heat shield jettison completion

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2. Controls

- a. ELS sequence arm command
- b. Window covers operate command
- c. Forward heat shield jettison command
- d. Drogue mortar fire command

A barometric pressure display will also be provided for event monitoring of baroswitch operation during reentry.

The operation of the earth landing system will be simulated in both automatic and manual modes. The controls and displays will be perceptually identical to those in the spacecraft and will perform the same functions. The displays and controls relative to the recovery phase of the mission are not applicable to the trainer and will be mocked up.

IN-FLIGHT TEST SYSTEM (IFTS)

Since the spacecraft maintenance and system test philosophy for IFTS utilization is under study, the functional capability for IFTS simulation will be as follows:

1. Control switches will be functional.
2. Readout displays will indicate a systems GO or NO GO condition.

VISUAL SIMULATION

Visual Related Tasks

Certain tasks of primary importance to mission success rely almost entirely on visual cues for their accomplishment. Training for these tasks must be provided before flight time for the crew members to become competent.

It is established that training of sufficient sophistication to produce qualified crews must be given. The total training should therefore include all predictable visual stimuli for which a crew response may be required. The distinct task training related to visual cues may be obtained as shown in Table 1. Operational procedures and task skill will be stressed in the Apollo Part Task Trainer.

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Table 1. Training Related to Visual Cues

Acquisition Method	Typical Equipment	Typical		Response Learned	Application to Apollo Mission
		Function	Visual Cues		
Apollo Part Task Trainer	Simulator modified to fit particular tasks	Orbit determination and IMU alignment	Telescope and sextant	Performance procedures and accuracy	Essential
		Navigation procedures	Telescope and sextant	Performance procedures and accuracy	Essential

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The Apollo Part Task Trainer is of particular value where considerable task drilling on an individual as well as full crew basis is required. The feature of adaptability of the part task trainer to changing task requirements makes it ideal for training use in extra mission occurrences such as abort (at varying times), critical orbit or trajectory deviations, return to earth without LEM crew, etc. It may be determined that several variations from normal mission tasks should be taught. The simulation of extreme mission deviations would be as easily accomplished as the changing of mission phases in the part task trainer due to its adaptability and readily replaceable surrounding equipment.

Visual Stimuli - Response Requirements

Response requirements are from single to multiple, simple to complex. The degree to which the response is learned in association with a visual stimulus will be from basic knowledge of expected response to conditional reflex or habit response. To achieve an automatic, habit response, considerable repetition over an extended period of time will be required. The standard tasks for which completion time is limited or critical should be learned and then drilled until they develop an intimate familiarity with these flight profiles and gain the conditioned response of being virtually automatic. This releases the active mind to judgements in other critical areas.

For this purpose the "feel" of the simulated stimuli-response (as minimum reaction or SCT-SXT controls) should be the phenomenal equivalence of the real craft. Due to the inherent limitation in the simulator of no weightlessness or disorientation, the crews burden of correlating the real flight requirements with the nearest training simulation should not be increased by too many omissions of visual stimuli.

Telescope and Sextant

Visual presentations shall be provided for the telescope and sextant sufficient to provide:

1. Positive primary training for crew members who have had no orbit experience
2. Transition training for crew members with orbit experience
3. Procedures training and exercise on a task basis

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The principal tasks involving telescope and sextant visual presentation which are unique while at the same time important to the Apollo mission are:

1. Orbit determination and IMU alignment in preparation for translunar or transearth injection
2. Position determination during translunar or transearth using landmark star or limb readings

The procedure for taking a navigational fix (Appendix B) shows that the final phase of this task requires great skill. Attitude drift must be controlled to keep the landmark line of sight within the sextant field of view while at the same time the selected star must be acquired in the other sextant line of sight using the slewing controls. Finally, both images must be simultaneously aligned.

Proficiency in this skill will require considerable practice by the crew members. Since attitude minimum reaction controls (3 degrees of freedom) affect both lines of sight while slewing controls (2 degrees of freedom) affect only one, the simulated image response will have to be carefully calibrated with each of these controls.

Figure 6 shows the assembly of the sextant-telescope simulation.

Scanning Telescope (SCT) Simulation

The appearance within the Command Module and the operating controls of the actual telescope will be duplicated in the training simulator (see Appendix B). The fidelity and resolution of the image presented to the telescope need be only as high as required to assure that the desired landmark and star can be determined by the crew member and presented to the sextant's view.

The scenes presented to the telescope during earth or moon orbit shall have the following characteristics.

1. Motion of the earth or lunar scene during orbit shall be limited to motion along the orbit plane. Previous alignment of the spacecraft X-Z plane with the orbit plane will be assumed.
2. Provision will be made in the telescope for a simulated roll of the spacecraft which would put the center line of sight of the telescope north or south of the orbit plane. The maximum latitudes that will be included within the field of view of the telescope will be from 60° north to 60° south latitude. The simulated roll of the craft

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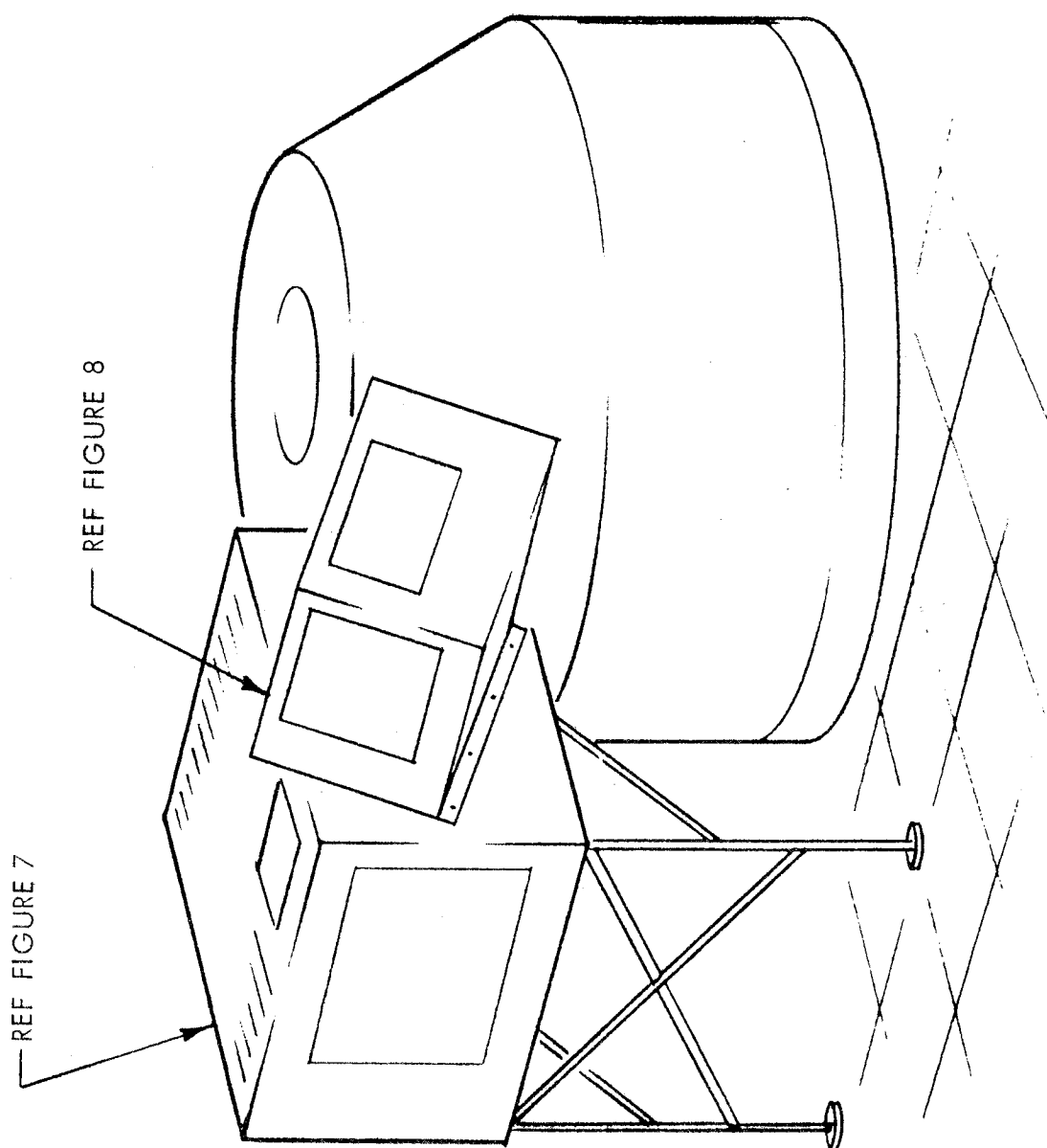


Figure 6. Visual Cue Attachments

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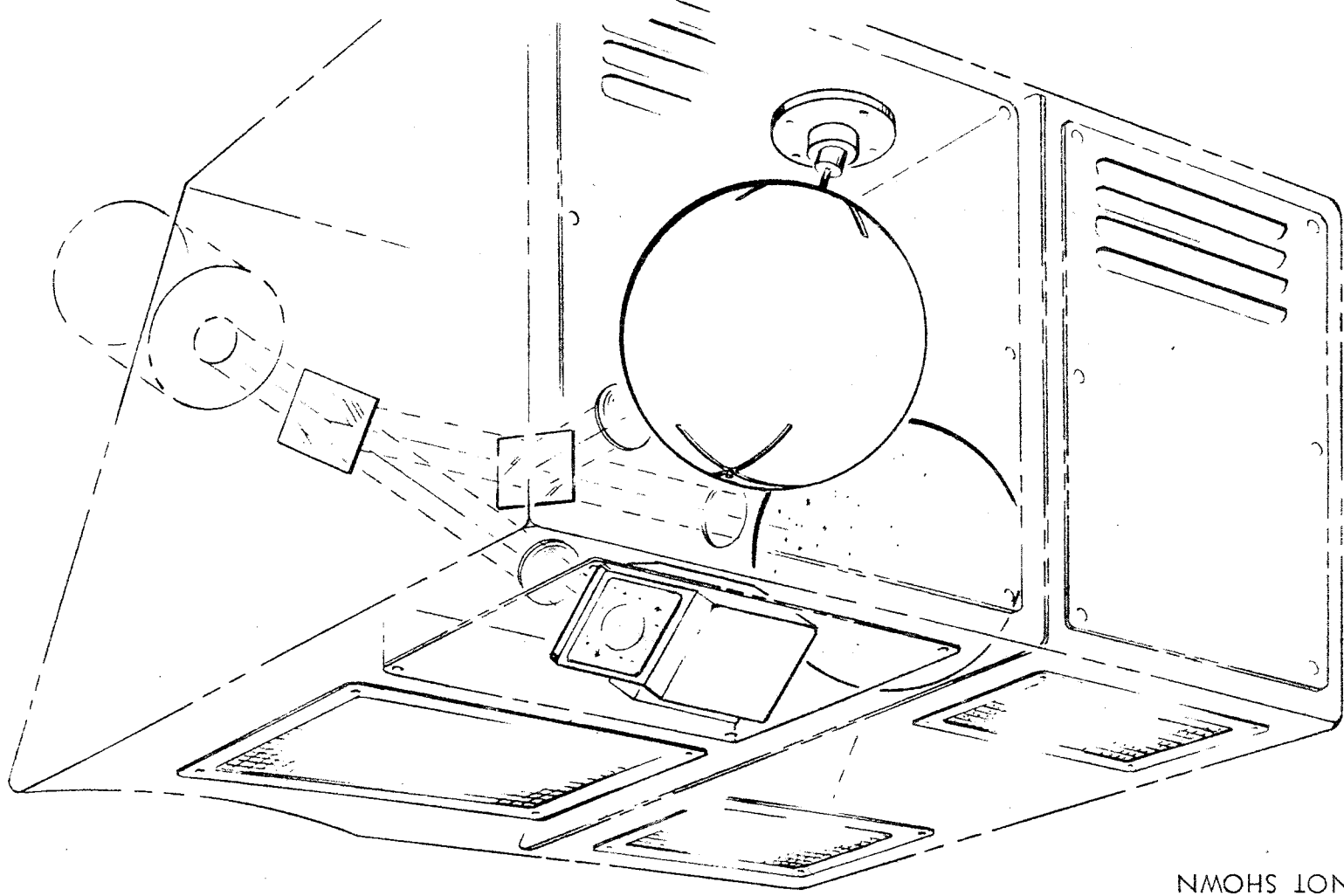
will be done by an auxiliary prism and single freedom mirror at the probe of the telescope. This is for simulation only and is not a part of the real craft telescope, but will be inserted to give north-south line of sight freedom to simulate the roll of the spacecraft.

3. The real craft trunnion axes freedom over earth or moon model will be simulated by an actual trunnion mirror. During orbit the center line of sight can be slewed up to the horizon in an east-west direction only. The limitation as given above for a north-south maximum freedom will place the center line of sight of the telescope a maximum of 30° north or 30° south for any orbit that will be inserted.
4. The model design (see Figure 7) shall be capable of having the simulated orbit changed before the task exercise is started. This is done by simply loosening the wing nuts that hold the single axis support for the model globe and moving the axis along a slot on a longitude meridian. The axis is always normal to the plane of the orbit and its latitude change will constitute a change in the orbit.
5. The slot indicated in (4) shall extend to 30° latitude away from the pole in four directions from the pole along the 0° , 90° , 180° , 270° meridian of longitude. This will keep the slot out of the field of view of the telescope in its maximum north-south position and yet provide capability of changing the orbit up to 30° north or south and in four possible modes around the earth.
6. No provision shall be made for yaw in the telescope scenes during orbit. However, limited roll will be simulated as in (2) and limited pitch will be simulated by increased motion of the trunnion mirror mentioned in (3). The simulated trunnion mirror will respond to the sum or difference of signals from both trunnion axis slewing control and pitch input to RCS. Trunnion axis readout instruments will respond only to trunnion slewing control, however.
7. A static non-identifiable star field will appear behind earth or moon in case the trunnion mirror moves part of the telescope field of view above the east or west horizon.
8. The albedo of white clouds is sufficiently greater than that of the ground to allow brightness from the disk section of the telescope generation to wash out the view of the earth landmarks (see Figure 7).

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Figure 7. Scanning Telescope Image Generator

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The instructor will be capable of washing out areas of the earth model to economically simulate cloud cover. This will be accomplished by switching on one or more of five small spotlights with irregular edges which are directed toward the back side of a disk of opal glass in the mid-course disk position near the first beam splitter.

9. Star field generation will be from a 24-inch-diameter celestial sphere. Point light star sources will be simulated from reflected light off small polished spheres imbedded in the celestial sphere. Since no telescope slewing or attitude sweep is required, the motion of the star field will be limited to transferring a given navigation star from the edge of the field of view to the center (30°). By limiting star field scenes containing navigational stars to 60° areas that do not include the earth, moon, or sun, occulting disks would be eliminated.

Approximately 30 percent of the star field (portion towards earth, moon, or sun) shall be excluded from any presentation. These regions will be used for economical supports, gimbal lock, etc.

10. A 24-inch-diameter earth model, in color but without relief features, shall be lighted by 18-inch fluorescent daylight tubes which are pivoted about earth model axis supports. Two on each side of optics pick up (N&S) will assure that no shadows of probe are projected on model. Their motion will thus follow the orbit instead of the ecliptic, but for economic reasons this is considered tolerable. The spherical star field will not be behind the simulated earth model, so no occulting disk is necessary for the dark side of the terminal. During orbit the spherical star field is used only for IMU alignment.
11. At least six landmarks on the earth model (more if extremely economical) will be accurate enough for use in orbit determination. Alternate selection will be possible.
12. At least three landmarks on the moon model (more if economical) will be used for orbit determination practice. The moon model shall be installed to replace the earth model for lunar orbit practice.

The scenes presented to the telescope during mid-course trajectory shall have the following characteristics:

1. There will be only three positions at which a disk presentation will be made of the earth and moon. These positions will simulate

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distances of approximately 50,000 miles, 120,000 miles, and 200,000 miles from the earth, as shown below.

Position	Earth Disk	Moon Disk	Landmarks Identifiable for Sextant Use	
			Earth	Moon
Near Earth (50,000 mi)	1	1	3	1 (or limb)
Mid way (120,000 mi)	1	1	2	2
Near Moon (200,000 mi)	1	1	1 (or limb)	3

- The visual display of the navigation task will start with the landmark to be used already within the field-of-view of the telescope. The procedure will require that the slewing controls be activated to resolve the telescope angles to 0° while the attitude of the craft is adjusted to put the landmark within reticle at the center that defines SXT field-of-view. The proper landmark that will be presented to the sextant will have been pre-selected from the fact that the particular landmark was already within the field of view of the telescope as determined by the electronic sensors. When the centering has been accomplished such that the landmark will appear within the sextant field of view, electronic sensors of the telescope position will then automatically turn on the light that presents the landmark half of the slide to the direct LOS of the sextant.
- The next step in the real task of gross attitude maneuver and search mode of the telescope for the proper star field, will be omitted visually. The very act of pushing the 25° offset mode switch will not put SCT in search mode but will change the scene presented to the telescope to a preselected celestial star field within which will be one or more navigation stars. The second part of the task thus started will be initiated by bringing the navigation star to the center of the telescope reticle by manipulating the telescope trunnion and shaft slewing controls. Upon acquiring the star within the field of view region of the sextant, the angle sensors will automatically turn on the part of the sextant scene which presents the navigation and surrounding stars.

The midcourse systems described above start with star or landmark within the field-of-view of the one power ocular of the telescope. The crew members will then respond to (1) place the object in the center of the one power, (2) change to three power, and (3) readjust the object in the center. This is the correct procedure to be included for proper sextant scene before transfer is made to the sextant.

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The task of IMU alignment uses two sets of stars to define the planes passing through the spacecraft (see Appendix B). This task will start visually with one of the stars already within the field of view of the telescope. The procedure will subsequently require the star to be moved to the center and transfer made to the sextant as before; but upon pushing the sextant mark button, the star field containing the second star will be presented to the telescope and the procedure will be repeated. Thus, search mode and gross attitude maneuvers have been visually deleted from the task for economy.

Sextant (SXT) Simulation

Sextant star scenes will be provided just for selected navigational stars sufficient for adequate training. A total solid angle of 5° for a scene will assure that when the sextant has been positioned for a fix and the edge of the scene is not visible, the brighter navigational star will be within the 1.9° field of view of the sextant. To provide training in discrimination between stars, the sextant 5° star scenes shall include those stars that would appear fairly bright in the 28 power sextant. From 10 to 50 stars within 5° field would include fields toward and normal to Milky Way.

The response of the scenes to the sextant and minimum reaction controls must be accurate enough to provide positive training transfer in this compound task.

The accuracy of the sextant simulation shall be compatible with that of the actual spacecraft. However, objects need not be accurate in spatial relationship. Use of the sextant during orbit is limited to star sightings for IMU alignment. Primary use is for navigation fixes during mid-course trajectory. The sextant presentations shall have the following characteristics (see Figure 8):

1. The spatial position of the sextant scene will be grossly slaved to the telescope scene. Thus, having an object in the upper right hand corner of the telescope reticle which defines sextant field of view will position the sextant object within that quadrant.
2. Current investigation indicates that an overall accuracy of plus or minus 20 seconds of arc between landmark and star would be sufficient to assure mission success. The simulation accuracy will have an upper limit of plus or minus 10 seconds of accuracy to provide the allowance of another 10 seconds of arc for human error. It is not herein assumed that minimum human error will be 10 sec of arc but a mechanical accuracy within 10 sec of arc would provide for this allowance.

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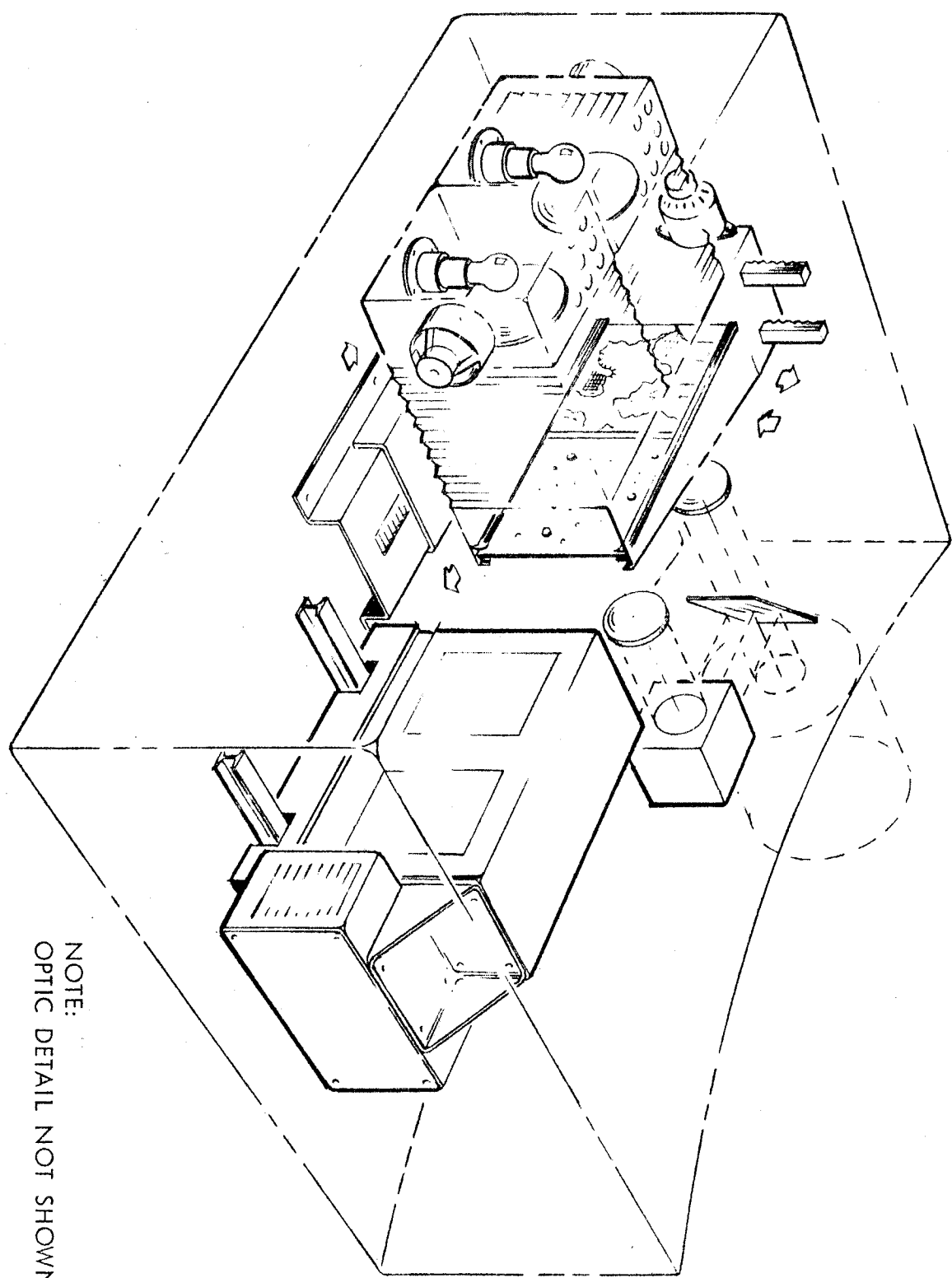


Figure 8. Sextant Image Generator

NOTE:
OPTIC DETAIL NOT SHOWN



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The high accuracy requirement for landmark to star will be achieved by simultaneous optical viewing of both lines of sight to a single plate upon which distance (simulating large angle) is kept constant.

3. Response of scene to Minimum Reaction Impulse Controls and Slewing Controls will be included but motion will be limited to keep the 1.9° field-of-view within a 5° solid angle scene.
4. Image generation and presentation will be by direct optics viewing a 5" x 10" slide. One 5" x 5" half for landmark and the other half for navigation star with surrounding lessor stars. Stars above magnitude 2.5 will be simulated by a small plane-convex lense attached to the light source side of the plate with the convex side out. It will thus gather light (amount depending on its diameter—1/4 inch and less) and focus it on the opposite near surface glass toward the object lense. This will approximate a point light source. The luminous intensity of a star will thus depend upon the size of the star lense, not the size of the hole below which it is mounted. The other non-identifiable lessor stars shall be tiny scribed holes in foil. Light source will be only approximately 6×10^{-2} to 6.8×10^{-1} lumens. The sextant plate requirements are as follows:

Position	Earth Landmark With Nav. Star Field	Lunar Landmark With Nav. Star Field
Near Earth (50,000 mi)	3	1 (moon limb & stars)
Mid-way (120,000 mi)	2	2
Near Moon (200,000 mi)	1 (earth limb & stars)	3

Any position (for IMU aline) will have two double star fields with one nav. star on each half.

Clouds will not be provided on sextant scenes, because it will be assumed that the telescope acquisition shift to alternate landmark will put the limited 5° max field of view of sextant outside of a cloud-covered area.

Scene Generation

Since the part task trainer does not require continuity or sequence beyond a single task the generation of scenes may be on short-term and short-area basis.

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Landmarks

The selection of landmarks for telescope and sextant presentation for orbit determination and navigation procedures is limited to about 10 percent of those considered necessary for full mission. Familiarity with other landmarks can be obtained from photographs taken at parking orbit distance in the case of earth or from telescope or future probe photographs in the case of the moon.

Stars

It is anticipated that familiarity with major star positions and constellations will have been previously learned.

AURAL SIMULATION

The aural simulation will provide a representation of the aural cues that the crew will hear during critical phases of the mission. The audible sounds will provide event, system function, and occurrence cues as important aids in decision making.

Such cues not only provide reassurance by their presence that all is well and a warning by their absence that all is not well, but they also serve as reminders that subsequent activities should be prepared for. Realistic aural effects are thus vitally and irrevocably linked to overall performance and are essential to a reliable training program.

For example, important cues generated by the Guidance and Navigation System during a reentry manual mode will be simulated.

Simulation of service propulsion engine operation, booster engine operation, launch escape tower jettison and reaction control system operation will be furnished. Aural cues associated with red warning lights also will be provided.

Preplanned sounds, as determined by a lesson plan, will be stored on tape and controlled by an event timer. Typical preplanned sounds are those generated by the booster engines during the launch phase.

Unscheduled sounds, as determined by crew activity, will be generated by electronic audio oscillators. Typical sounds of this category are those generated by reaction jets during attitude maneuvers.

The design of equipment devised for aural simulation will permit modification, deletions, and addition of aural equipment as associated changes are made in the spacecraft systems.

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The output of the aural simulation will terminate at the loud-speaker in the Command Module or at the head sets of the crew. Aural cues terminating in the head sets will pertain to communication sounds only.

OTHER DISPLAYS AND CONTROLS

The following displays and controls will also be provided in addition to those required for operation of the spacecraft systems.

1. Separation sequence control
2. Radiation warning display*
3. Caution indication
4. In-flight test control
5. Integrated display unit
6. Booster situation indicator
7. S/M quadrant temperature indicator
8. Entry monitoring indicator
9. Lighting system
10. Rendezvous display

The displays and controls will, in general, be functional replicas of actual equipment. Those displays and controls which are not normally used in the trainer simulated mission will be realistic mock-ups of actual equipment.

Separation Sequence Control

The following controls and displays will be provided for the separation sequence control.

1. Event indication
 - a. Sequence ready
 - b. S/M adapter separation sequence completion

*Indicates an item of equipment which will be nonfunctional on the trainer.

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- c. Adapter jettison sequence completion
- d. S-IV/LEM separation sequence completion*
- e. Shroud jettison sequence completion*
- f. LEM jettison sequence completion*
- g. S/M jettison sequence completion

2. Controls

- a. Sequence arm command
- b. S/M adapter jettison sequence initiate command
- c. Adapter jettison sequence initiate command
- d. S-IV/LEM separation sequence initiate command*
- e. S-IV retrofire command*
- f. Shroud jettison sequence initiate command*
- g. LEM jettison sequence initiate command*
- h. LEM retrofire command*
- i. S/M jettison sequence initiate command
- j. S/M retrofire command

Radiation Warning Display

A mock-up of the display which is used to indicate quantitative radiation dosage rate and accumulated dosage will be provided.

Caution Indication

Displays will be provided to notify the crew of major system malfunction.

Warning red lights will signify emergency conditions which will jeopardize crew safety unless immediate action is taken.

*Indicates an item of equipment which will be nonfunctional on the trainer.

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An audible warning will be presented in conjunction with the visual display warning. Caution amber lights will signify conditions outside the limits of system design performance and requires corrective action, but does not necessarily imply that immediate action be taken. This display will not be associated with an audible warning.

These displays will be initiated by the instructor or the computer.

In-Flight Test Control

The following control functions shall be provided for in-flight test system operation:

1. System power ON-OFF command
2. Scan mode selection (3 modes)

Integrated Display Unit

Means shall be provided to display a limited amount of recorded information consisting of measurement test point identification, test, maintenance, and troubleshooting procedures information.

Booster Situation Indicator

Displays will be provided to notify the crew of booster system malfunction and occurrence of major booster events not detectable by direct sensory means. These displays will be initiated by the instructor or the computer.

S/M Quadrant Temperature Indicator

This indicator, which displays readings from the temperature sensors in the four quadrants of the S/M, will be manually controlled by the instructor, and the four push button type selector switches for each quadrant will be operable.

Entry Monitoring Indicator

A display which is not dependent upon the stabilization and control system or the guidance and navigation system for situation information will be provided, capable of displaying the acceleration-time history and the relative orientation of the aerodynamic lift vector of the spacecraft during entry. The display will incorporate means to repeat the commanded roll orientation for comparison with actual orientation. The purpose of the display will be to monitor the entry situation during either machine or

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manually commanded maneuvers and shall interface with the simulation computer complex.

Lighting System

Lighting control panels for the part task trainer will be located on the lefthand and righthand consoles. The following control functions will be provided on each console for the lighting system.

1. Annunciator control
2. Secondary floodlight ON-OFF command
3. Primary floodlight intensity adjust
4. Integral intensity adjust
5. Means will be provided, at the instructors' console, to duplicate the lighting control panels.

Rendezvous Display

The rendezvous display is not defined at this date. It will be included in later reports as information becomes available.

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IV. MECHANIZATION EQUATIONS

In this section mechanization equations for the Apollo Part Task Trainer are presented. The section is broken down into atmospheric and extra-atmospheric flight phases, for expository reasons. Symbols used in the equations are defined in Table 2.

ATMOSPHERIC PHASES

Mechanization equations for the launch and entry phases of the Apollo mission are presented below. These phases begin or end above the sensible atmosphere, with atmospheric effects being of prime importance. The training mission associated with the launch phase begins at any desired time between T-20 to T-0 minutes, and is continuous through orbital insertion. In case of abort prior to orbital insertion, the training mission will continue through drogue chute deployment. The entry phase begins at an altitude between 600 K to 400 K ft, and ends at drogue chute deployment. Note that the launch phase, as defined above, may include the entry phase (in case of abort).

It is not planned to permit the training mission to start at arbitrary altitudes during the entry phase, except for the launch abort case. This requirement is imposed because of the difficulty in setting up initial conditions for the dynamic entry simulation. The launch phase will not be allowed to begin after T-0 because any advantage this may have does not justify the entailed complexity in problem setup.

Launch Phase Equations

In this section the equations associated with the boost trajectory and orbital injection are presented.

Boost Trajectory

A pre-programmed trajectory is proposed for the powered flight phase. A number of such trajectories are required in order to allow for booster malfunctions or changes in booster performance. The parameters defining the trajectory will be fed into the digital computer prior to initiation of the mission. Position and velocity data will be stored either in inertial or relative (to moving earth) coordinate frames (see Figure 9). In either case

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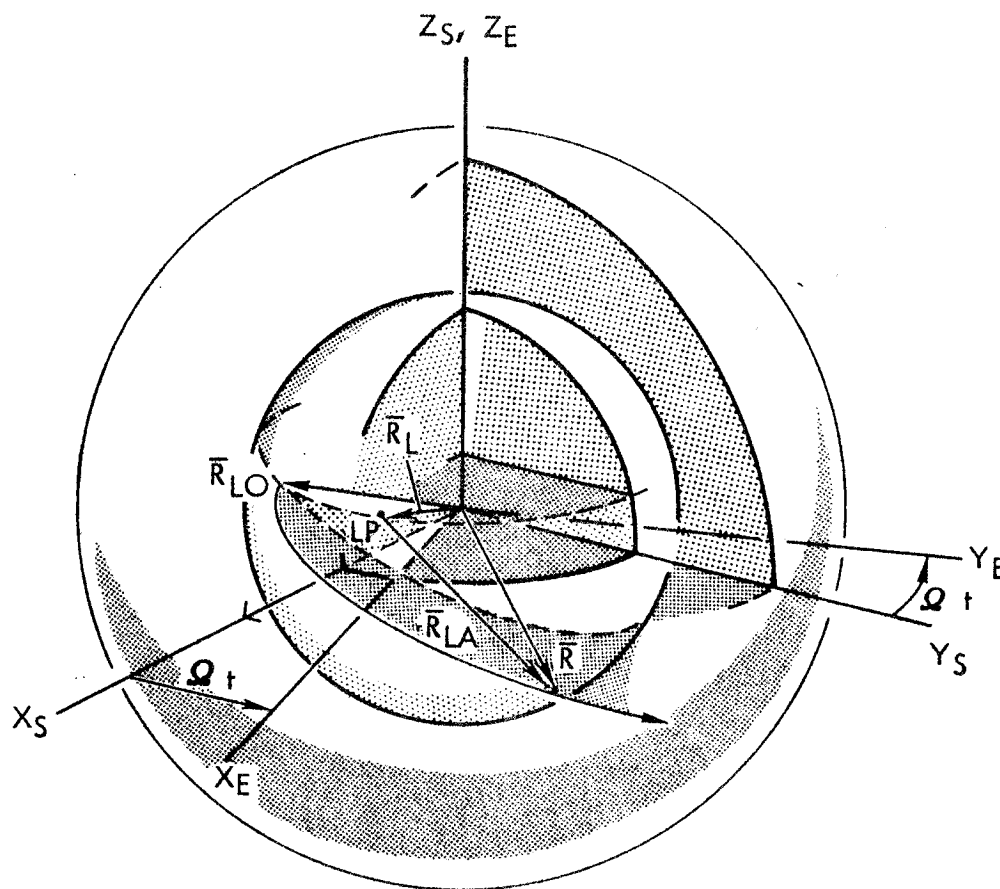


Figure 9. Boost Trajectory Coordinates

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Table 2. Definition of Symbols

Symbol	Definition
\bar{R}	Position vector of spacecraft (from earth center)
$\bar{\Omega}$	Angular velocity of earth
$\left(\frac{d}{dt}\right)_S$	Derivative in "inertial coordinate system"
$\left(\frac{d}{dt}\right)_E$	Derivative in coordinate system rotating with the earth
\bar{R}_L	Vector from earth center to point on earth from which launch occurred (constant vector in E Frame)
\bar{R}_{LA}	Vector from (moving) launch point to spacecraft
X_S, Y_S, Z_S	Inertial frame, located at center of earth, $X_S Z_S$ plane contains the Launch Point
\bar{R}_{Lo}	Vector from earth center to inertial launch point (constant vector in inertial frame)
X_E, Y_E, Z_E	Earth-centered frame which rotates with the earth
$[A]$	Matrix defined in equations (1)
$\bar{a}_0 \dots \bar{a}_4; \bar{b}_0 \dots \bar{b}_4$	Vector constants defined in equations (2)
$\bar{\xi}, \bar{\eta}, \bar{\zeta}$	Unit vectors along the roll, pitch and yaw axes
α_T	Total angle of attack
V_a	Velocity relative to atmosphere
q	Dynamic pressure
ρ	Atmospheric density
h_S	Scale height
\bar{V}_g	Velocity to be gained

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Table 2. Definition of Symbols (Cont.)

Symbol	Definition
\bar{V}_c	Correlated velocity (or required velocity)
\bar{V}	Present velocity
μ_E	GM
G	Gravitational constant
M	Mass of earth
\bar{R}_I	Vector from earth center to injection point
R_o	Radius of earth
h_o	Orbit altitude
\bar{i}_p	Unit vector normal to orbit plane
$\bar{\omega}$	Attitude rate vector (command)
K, K_1	Gain constants
\bar{g}	Gravitational acceleration
\bar{a}_T	Rocket thrust
\bar{a}	Drag acceleration
a	$ \bar{a} $
C_D	Drag coefficient
C_{D_o}	Drag coefficient at equilibrium condition, a constant
C_L	Lift coefficient
C_{L_o}	Lift coefficient at equilibrium condition, a constant
C_Y	Aerodynamic side force coefficient

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Table 2. Definition of Symbols (Cont.)

Symbol	Definition
C_l	Aerodynamic roll moment coefficient
C_m	Aerodynamic pitch moment coefficient
C_n	Aerodynamic yaw moment coefficient
c.g.	Center of gravity
α	Angle of attack
β	Sideslip angle
ϕ	Roll angle
\bar{g}	Gravitational acceleration
h	Altitude
h_S	Atmospheric constant (scale height)
K	Guidance system constant
K_L	Guidance system constant
K_E	Guidance system constant
\bar{L}	Lift force
L_i	In-plane lift
L_o	Out-of-plane lift
L/D	Lift to drag ratio
m	Mass of vehicle
p	Angular rate about body roll axis
q	Angular rate about body pitch axis
r	Angular rate about body yaw axis



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Table 2. Definition of Symbols (Cont.)

Symbol	Definition
D	Track range along great circle path
D_{go}	Range to go
R	Radial distance of vehicle from center of earth
\bar{V}	Velocity relative to atmosphere
V	$ \bar{V} $
V_o	Orbital velocity
W	Weight of vehicle
x, y, z	Body axis
I_X, I_{XY} , etc.	Elements of moment of inertia matrix
Q	Dynamic pressure
\bar{T}	Moments due to reaction jets
S	Aerodynamic area
ϵ_1	A guidance constant
ϵ_2	A guidance constant
ρ	Atmospheric density
D_B	Range achieved during ballistic mode
D_Y	Range achieved during constant flight path angle mode
D_{SG}	Range achieved during equilibrium glide mode
D_C	Cross range
D_R	Defined in equation (16), page 70

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Table 2. Definition of Symbols (Cont.)

Symbol	Definition
$X_c Y_c Z_c$	Coordinate frame defined in paragraph preceding equation (1), page 75
$X_s Y_s Z_s$	Coordinate frame defined on page 49
[B]	Matrix involving i and Ω , inclination or orbit plane and longitude of ascending node, respectively.
p, q, r	Angular rates about body axis
$\dot{p}, \dot{q}, \dot{r}$	Angular accelerations about body axis
$\Delta L, \Delta M, \Delta N$	Reaction jet thrust components
[I]	Moment of inertia matrix (all elements are assumed constant)
\bar{R}	Vector from earth center to spacecraft
M_e	GM
G	Gravitational constant
M	Mass of the earth
T	Time of passage through ascending node
\bar{V}_c	Correlated velocity
\bar{V}_g	Velocity to be gained
\bar{V}	Present velocity
\bar{R}_T	Vector to aim point
t_F	Time of flight (injection to hit point)
\bar{I}_v, \bar{I}_n	Unit vectors (\bar{I}_n is normal to \bar{I}_v)
γ	Angle between \bar{R} and \bar{V}

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Table 2. Definition of Symbols (Cont.)

Symbol	Definition
Subscripts	
0	Initial condition
11	Point where equilibrium glide is initiated
B	Ballistic mode
C	Command
eq	Equilibrium
ex	Exit
f	Final or recovery interface
i	ith sample
MAG	Magnitude
MAX	Maximum
MIN	Minimum

transformations will be made to the other coordinate frame in the digital computer. The equations are:

$$\left(\frac{d\bar{R}}{dt}\right)_S = \left(\frac{d\bar{R}}{dt}\right)_E + \bar{\Omega} \times \bar{R}$$

$$\left(\frac{d\bar{R}}{dt}\right)_E = \left(\frac{d\bar{R}_{LA}}{dt}\right)_E = \left(\frac{d\bar{R}}{dt}\right)_S - \bar{\Omega} \times (\bar{R}_L + \bar{R}_{LA}) \quad (1)$$

$$\bar{R} = \bar{R}_{LA} + \bar{R}_L$$

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C [REDACTED]

$$\bar{R} = \begin{bmatrix} X_S \\ Y_S \\ Z_S \end{bmatrix} = [A] \begin{bmatrix} X_E \\ Y_E \\ Z_E \end{bmatrix} = \begin{bmatrix} \cos \Omega t & -\sin \Omega t & 0 \\ \sin \Omega t & \cos \Omega t & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_E \\ Y_E \\ Z_E \end{bmatrix}$$

It is not presently known in what coordinate frame the position and velocity data will be expressed. It will be given in terms of one of the coordinate frames described above. Position and velocity data will be displayed in terms of either system (or relative to the launch point), through use of equations (1) and the input data. It is assumed that the position and velocity will be expressed as polynomials in t , time:

$$\begin{aligned} \bar{R} &= \bar{a}_0 + \bar{a}_1 t + \bar{a}_2 t^2 + \bar{a}_3 t^3 + \bar{a}_4 t^4 \\ \bar{V} &= \bar{b}_0 + \bar{b}_1 t + \bar{b}_2 t^2 + \bar{b}_3 t^3 \end{aligned} \quad (2)$$

The (vector) constants \bar{a}_0 , \bar{b}_0 , and so on, would be part of the pre-programmed trajectory data. The trajectory data will also include attitude as a function of time. Under certain assumptions as to guidance and control, such data would not be required; however, this attitude information will also be stored in the computer as part of the trajectory data:

$$\begin{aligned} \bar{\xi} &= \bar{\xi}(t) \\ \bar{\eta} &= \bar{\eta}(t) \\ \bar{\zeta} &= \bar{\zeta}(t) \end{aligned} \quad (3)$$

$$|\bar{\xi}| = |\bar{\eta}| = |\bar{\zeta}| = 1$$

Where $\bar{\xi}$, $\bar{\eta}$, and $\bar{\zeta}$ are unit vectors along the roll, yaw and pitch axes. These unit vectors may be transformed exactly as in equation (1), and may

[REDACTED]

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be expressed in either coordinate system. Total angle of attack, α_T , would be computed from velocity with respect to the air mass \bar{V}_a as follows:

$$\alpha_T = \cos^{-1} \left[\frac{\bar{V}_a \cdot \bar{\xi}}{V_a} \right] \quad (4)$$

On the other hand, it can be stored as part of the trajectory data. It is recommended that dynamic pressure can be computed as needed using the formula,

$$q = \frac{1}{2} \rho V_a^2 \quad (5)$$

Density will be obtained from a stored table.

The parameters discussed above define the required trajectory information. These parameters are needed for two basic reasons:

1. They permit displays of trajectory data to the crew.
2. They allow initial conditions to be set up for abort maneuvers.

The digital computer will be used to store these parameters and to perform the required transformations for display purposes and analog computer inputs. The analog computer will be used to "track" these parameters so that abort may be initiated at any time. It has been tentatively decided that the rotational equations of motion should be solved in the analog computer during an abort maneuver. The digital computer will be used to solve the translational equations of motion, to transform data for display, and to generate certain command functions (e.g., attitude) in automatic guidance modes. When manual control is being exercised, these commands will be initiated by the crew, based on the information displayed to them.

Orbit Injection

During the boost phase just prior to injection the crew will be observing \bar{V}_g , the velocity to be gained vector, plus perhaps other digital data such as position information. In addition to such digital displays, analog displays (e.g., attitude ball) will be presented. The equations given below will be used primarily to generate the digital (simulated AGC) displays.

The desired earth orbit is known prior to launch. Let its orientation be defined by the unit vector \bar{i}_p , which is normal to the orbital plane; and

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let the orbital altitude be denoted by h_o . Let the orbital velocity be denoted by \bar{V}_c , the present velocity by \bar{V} ; then

$$\bar{V}_g = \bar{V}_c - \bar{V} \quad (6)$$

is the velocity to be gained. Circular speed is

$$|\bar{V}_c| = V_c = \sqrt{\frac{\mu_E}{R_I}} \quad (7)$$

where

$$R_I = |\bar{R}_I| = R_o + h_o \quad (8)$$

R_o = radius of earth

The vector \bar{R}_I lies in the orbital plane, and by definition, is the injection point (see Figure 10).

Since the orbit is circular by assumption,

$$\bar{V}_c \cdot \bar{R}_I = 0 \quad (9)$$

Furthermore,

$$\bar{V}_c \cdot \bar{i}_p = 0 \quad (10)$$

Equations (8), (9) and (10) define \bar{V}_c , assuming \bar{R}_I is known. Now

$$\bar{R}_I \cdot \bar{i}_p = 0 \quad (11)$$

and therefore only one more relation is needed to define \bar{R}_I . This relation is obtained by a prediction process. Given present position, velocity and acceleration, it is possible to adjust \bar{R}_I (rotate it in the orbit plane) and thereby predict the injection point.

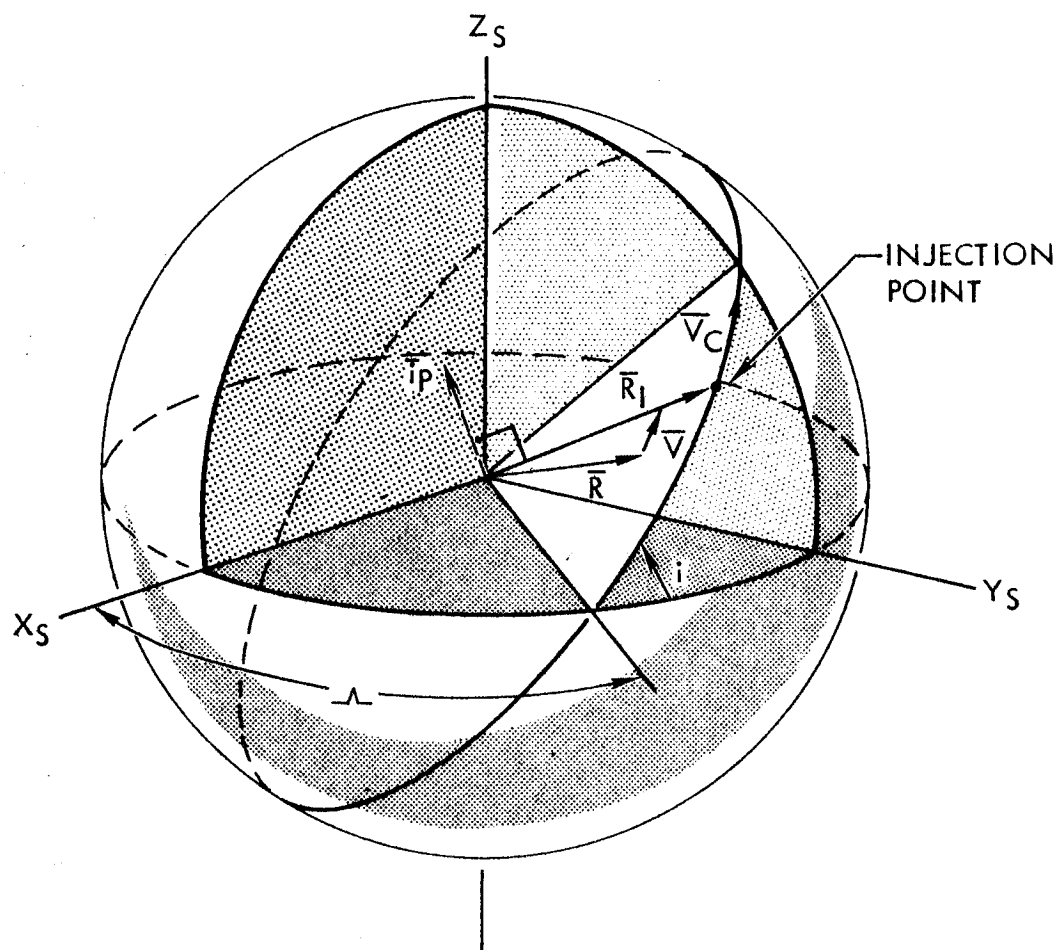


Figure 10. Orbital Injection Coordinates



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The control loop is closed through the \bar{V}_c calculation such that lateral (out-of-plane) position and velocity errors are nulled at the same time the in-plane errors are nulled. Attitude control could be simulated using a typical cross product type of pitch and yaw control:

$$\bar{\omega} = K \frac{\bar{V}_g \times \dot{\bar{V}}_g}{V_g^2} \quad (12)$$

K is a gain parameter (not necessarily a constant). The angular rate vector $\bar{\omega}$ is resolved in body axes to give the desired pitch and yaw rates (the roll component is redundant, and is not used).

The scheme outlined is iterative in the sense that the calculations must be repeated up to cutoff to achieve an accurate injection. They are not iterative in the sense that an iteration must be performed in a given computational cycle. It will be noted that the \bar{V}_c calculation is relatively simple, and hence also the \bar{V}_g calculation. Most of the inherent difficulty of the problem has been transferred to the problem of determining the orientation of \bar{R}_I in the orbit plane. This calculation must be performed using presently available data, which changes with time; and therefore a repetitive type of solution is required. The final prediction is essentially the result of a sequence of approximations.

Engine cutoff is signalled when V_g goes to zero. One last point should be mentioned relative to \bar{V}_g : near cutoff this vector is very nearly equal to the negative of the applied thrust. This follows from equation (9),

$$\frac{d\bar{V}_c}{dt} \cdot \bar{R}_I + \bar{V}_c \cdot \frac{d\bar{R}_I}{dt} = 0 \quad (13)$$

but

$$\frac{d\bar{R}_I}{dt} = \bar{V}_c \quad (14)$$

when in orbit; therefore,

$$\frac{d\bar{V}_c}{dt} \cdot \bar{R}_I = -V_c^2 = -\frac{\mu E}{R_I} \quad (15)$$

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and

$$\bar{g} \cdot \bar{R}_I = - \left(\frac{\mu_E}{R_I^3} \bar{R}_I \right) \cdot \bar{R}_I = - \frac{\mu_E}{R_I} \quad (16)$$

Therefore, near injection,

$$\frac{d\bar{V}_c}{dt} = \bar{g} \quad (17)$$

From equations (6) and (17),

$$\frac{d\bar{V}_g}{dt} = \frac{d\bar{V}_c}{dt} - \frac{d\bar{V}}{dt} = \bar{g} - (\bar{g} + \bar{a}_T) = -\bar{a}_T \quad (18)$$

since

$$\frac{d\bar{V}}{dt} = \bar{a}_T + \bar{g} \quad (19)$$

 \bar{a}_T = rocket thrust

Equation (12) becomes

$$\bar{\omega} = K_1 \bar{a}_T \times \bar{V}_g \quad (20)$$

where

$$K_1 = \frac{K}{(V_g)^2}$$

Reentry Phase

In the reentry phase, the Guidance and Navigation System must place the returning vehicle at approximately the correct earth coordinates and must limit the reentry path angle to within some permissible range of values. The entry angle is defined to be the angle between the flight path and the local horizontal, measured positive downward. The path angle must not be so shallow as to allow the vehicle to elude capture, nor so steep that intolerable peak deceleration is encountered. At one extreme, the minimum entry angle is such that the vehicle will skip to the top of the atmosphere, but still proceed to target. If the entry angle is smaller than this the vehicle will not be captured. At the other extreme, the maximum entry angle is the angle

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beyond which the deceleration is not tolerable and beyond which the maximum lift correction will still place the vehicle short of target.

In dealing with the reentry simulation and training problem, a number of conditions are assumed to exist for the sake of a preliminary formulation. The earth is taken to be a non-rotating sphere; the vehicle position, velocity, and alignment are given from the previous phase of the mission and the target coordinates are specified.

Reentry cue control will be based upon a hybrid, six degree of freedom, simulation of the controlled performance of the Apollo capsule in the atmosphere. The moment and acceleration equations will be solved by the analog computer, and the atmosphere and the pitch and yaw stability loops will be simulated by the analog computer. If the required solution rates permit, the acceleration will be integrated by the digital computer and a smoothed velocity output obtained. Otherwise, the integration will be analog. Velocity will be integrated and the components of distance in the various coordinate systems will be obtained by the digital computer. The moment equations will be solved in the body axis coordinate system to reduce the moment cross coupling. The guidance equations will be solved in local level geocentric coordinates.

To facilitate training in malfunction detection, the simulation will permit the opening, in any combination, of the guidance and stability loops.

Vehicle Dynamics

Flight path control of the Command Module during entry is achieved by controlling the relative magnitudes of the vertical and horizontal components of the lift vector. When sufficient aerodynamic pressure is encountered, the aerodynamic moments will tend to stabilize the spacecraft with the blunt end forward. Since the spacecraft c.g. is offset from the body center line, an asymmetric equilibrium condition (with respect to the relative wind) results; this asymmetric attitude gives rise to an aerodynamic lift force, which can be used to alter the reentry trajectory (see Figure 11).

Assuming a set of body axes chosen such that the moments and side force vanish when they are aligned with the wind axis, we may write the equations of motion:

$$m(\dot{V}_x + q V_z) = -C_D Q + W_x$$

$$m(\dot{V}_y + r V_x - q V_z) = C_Y Q + W_y$$

$$m(\dot{V}_z - q V_x) = C_L Q + W_z$$

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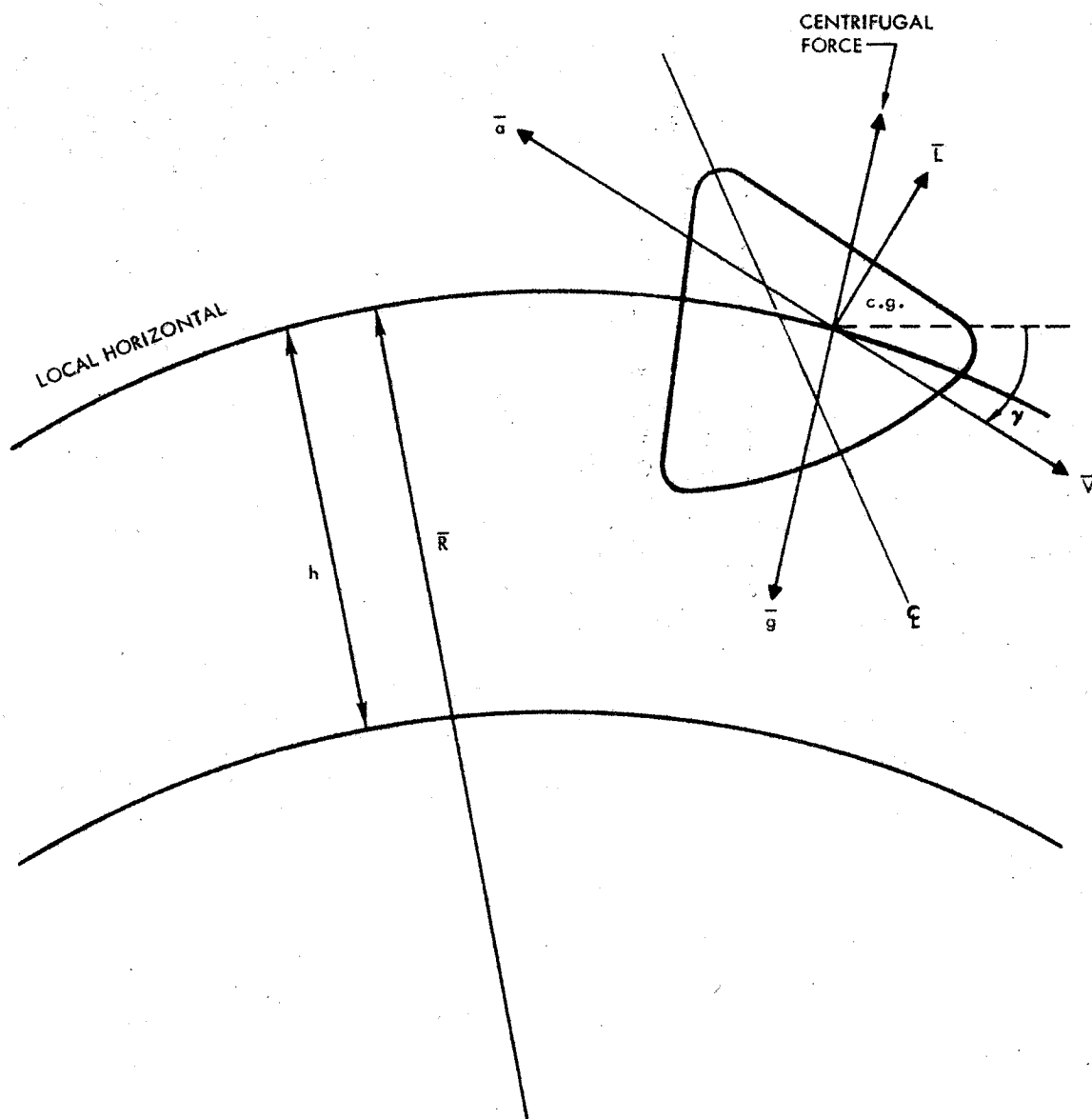
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Figure 11. Spacecraft Attitude

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$$\dot{p}I_x - \dot{r}I_{xy} = C_l Q + T_x$$

$$\dot{q}I_y = C_m Q + T_y$$

$$\dot{r}I_z - \dot{p}I_{xz} = C_n Q + T_z$$

where

$$Q = 1/2 \rho V^2 S$$

$$W = W_0 \text{ or } g - \text{constant}$$

Density will be obtained from a stored table.

Assuming small oscillations about the stable orientation, the aerodynamic parameters can be expanded:

$$C_D = C_{D0} + \frac{\partial C_D}{\partial \alpha} d\alpha + \frac{\partial C_D}{\partial \dot{\alpha}} d\dot{\alpha}$$

$$C_Y = \frac{\partial C_Y}{\partial \beta} d\beta + \frac{\partial C_Y}{\partial \phi} d\phi$$

$$C_L = C_{L0} + \frac{\partial C_L}{\partial \alpha} d\alpha + \frac{\partial C_L}{\partial \dot{\alpha}} d\dot{\alpha}$$

$$C_l = \frac{\partial C_l}{\partial \beta} d\beta + \frac{\partial C_l}{\partial \dot{\beta}} d\dot{\beta} + \frac{\partial C_l}{\partial \phi} d\phi$$

$$C_m = \frac{\partial C_m}{\partial \alpha} d\alpha + \frac{\partial C_m}{\partial \dot{\alpha}} d\dot{\alpha}$$

$$C_n = \frac{\partial C_n}{\partial \beta} d\beta + \frac{\partial C_n}{\partial \dot{\beta}} d\dot{\beta} + \frac{\partial C_n}{\partial \phi} d\phi$$

The initial values and the coefficients of the incrementals are assumed to be constant. The assumptions made in writing the above equations (i.e., negligible cross-coupling and nonlinearity) will be investigated further. The intent here is to simplify the problem as much as possible while retaining those factors which will be noticeable to the crew.

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Reentry Guidance (Primary)

The path is symbolically illustrated in Figure 12. The vehicle enters the atmosphere at point (1) with a maximum velocity approximately equal to 36,000 ft/sec and a flight path angle of γ_0 . The event sequence is described below:

- (1) Enter the atmosphere with lift directed away from the earth (zero roll angle) until the vertical descent is arrested.
- (2) From this point, predict range capability in flying a schedule of constant flight path angle, or constant altitude followed by equilibrium glide. Command a positive vertical velocity (away from the earth) until the desired range can be obtained. This vertical velocity is limited to a safe value that will ensure that the vehicle does not skip out of the atmosphere, but large enough to guarantee the range required.
- (3) Initiate the range control when the range capability is attained. This is accomplished in some cases by a constant altitude phase with a range loop closed. The very short range cases are flown with the downward vertical velocity limited so that a "g" limit will not be exceeded.
- (4) Finally, fly an equilibrium glide trajectory with range control referred to a nominal trajectory. Equilibrium glide is a trajectory wherein the path angle and path angle rate are assumed small enough so that vertical lift equals weight minus centrifugal force.

Primary reentry guidance for Apollo will be fully automated. It will utilize lift orientation to control an iteratively predicted range. Longitudinal range control requirements will determine the magnitude of the bank angle, but the direction of the bank angle may be used to control lateral motion by making a sequence of "S" turns.

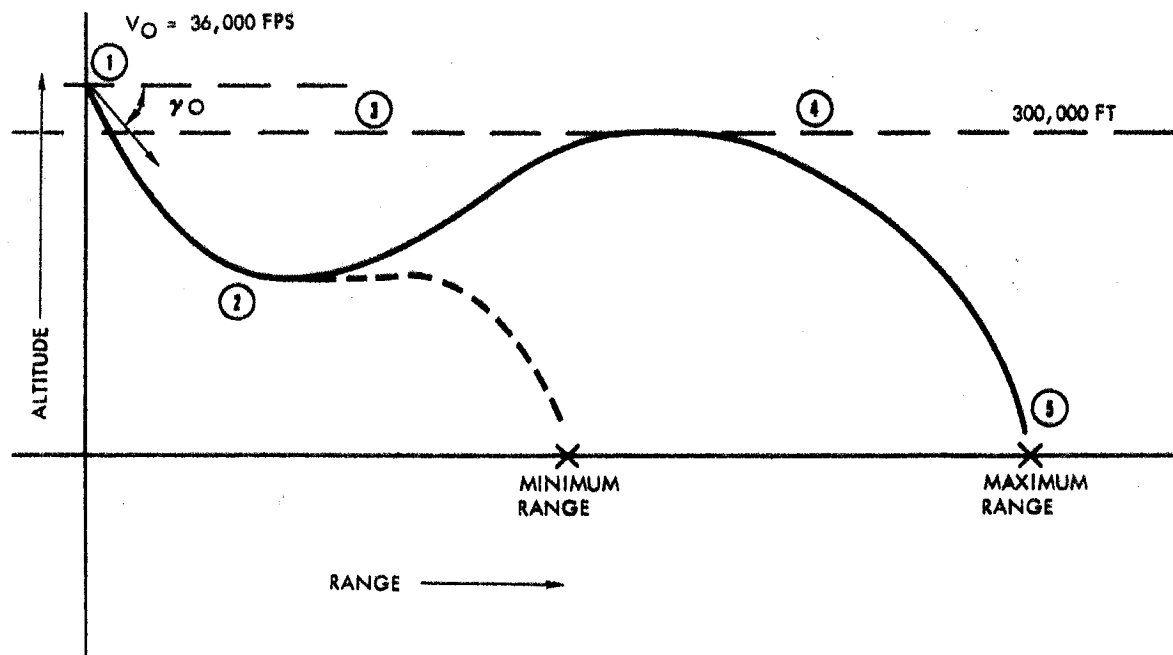
The MIT reentry guidance scheme will be used in the trainer; however, complete information is lacking and therefore a typical scheme is presented below. This scheme separates the trajectory into four guidance regimes: "entry," "pull out," "constant flight path angle," and "equilibrium glide."

Range control is not exercised during entry (the lift being fixed in the vertical plane) in order to insure safe passage through the "survival phase."

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- ①—② : ENTRY REGIME
② : PULL OUT
③—④ : CONSTANT FLIGHT PATH ANGLE AND/OR
CONSTANT ALTITUDE REGIME
④—⑤ : EQUILIBRIUM GLIDE REGIME
⑤ : PARACHUTE DEPLOYMENT



NOTE: THIS
ILLUSTRATION IS
SYMBOLIC ONLY

Figure 12. Entry Path

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This control regime is terminated when the vertical velocity \dot{h} has increased to some fixed threshold value ϵ_1 . At this time a roll angle ϕ_{MAG} is computed:

$$\phi_{MAG} = \cos^{-1} \left[\frac{(L/D)_{eq}}{(L/D)_{MAX}} \right] \quad (1)$$

where

$$(L/D)_{eq} = \frac{-\frac{V^2}{R} + g}{a} \quad (2)$$

This calculation continues, and the corresponding roll is commanded, until \dot{h} exceeds a predetermined value ϵ_2 . As noted earlier, the sign of the roll command is determined by the lateral maneuver requirements. No range prediction is made during this early roll maneuver.

When $\dot{h} \geq \epsilon_2$, the system enters the constant flight path angle regime, and an altitude rate command \dot{h}_c is iteratively calculated:

$$\dot{h}_c = \dot{h}_{exi} \frac{V_i}{V_{exi}} \quad (3)$$

where

$$\dot{h}_{exi} = \frac{V_o^2 - V_{exi}^2}{V_{exi}} \left[\frac{1 - \cos \left(\frac{D_{Bi}}{R_o} \right)}{\sin \left(\frac{D_{Bi}}{R_o} \right)} \right] \quad (4)$$

$$D_{Bi} = D_{goi} - D_{\gamma i} - D_{SGi} \quad (5)$$

$$D_{SGi} = \frac{R_o}{2} (L/D)_{NOM} \ell_n \left[\frac{1}{1 - \frac{(V_{exi})^2}{V_o^2}} \right] \quad (6)$$

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$$p_{ex_i} = \left[\frac{1}{(V_{ex_i})^2} - \frac{1}{V_o^2} \right] \frac{.2W}{S(C_L)_{MAX}} \quad (7)$$

$$Dy_i = h_s \frac{V_i}{h_i} \ln \left[\left(\frac{2a_i}{g p_{ex_i} (V_i)^2} \right) \frac{W}{C_D S} \right] \quad (8)$$

$$V_{ex_i} = V_i \exp \left[\frac{a_i h_s}{V_i h_i} \right] \quad (9)$$

The sequence of equations (3) through (9) are solved in reverse order, except that (7) is solved before (8). Equation (4) insures that uncontrolled skipout will be avoided.

The altitude rate command \dot{h}_c is limited to satisfy the survival boundary conditions,

$$\dot{h}_{MIN} \leq \dot{h}_c \leq \dot{h}_{MAX} \quad (10)$$

where

$$\dot{h}_{MIN} = \frac{2h_s g_{MAX}}{V_i} \quad (11)$$

$$\dot{h}_{MAX} = \frac{h_s a_i / V_i}{\ln [V_i / V_{i MAX}]} \quad (12)$$

This process continues until either

$$D_B \leq 0 \text{ and } V > V_{11} \quad (13)$$

or

$$D_B \leq 0 \text{ and } V < V_{11} \quad (14)$$

If inequalities (13) are satisfied, the constant altitude regime is entered; if inequalities (14) are satisfied, the equilibrium glide regime is entered.

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During the constant altitude regime, an altitude rate command is calculated:

$$\dot{h}_{Ci} = K_E (D_{go} - D_R) \quad (15)$$

where

$$D_R = 1/2 R_o (L/D)_{NOM} \left[\ln \left(\frac{1}{1 - \frac{(V_{11})^2}{V_o^2}} \right) \right]^{-1} + \frac{V_i^2}{a_i} \ln \left(\frac{V_i}{V_{11}} \right) + \frac{2 h_s}{(L/D)_{MAX} \left(1 - \frac{(V_i)^2}{(V_o)^2} \right)} \quad (16)$$

This command is limited according to equations (10) through (12) when

$$D_B \leq 0 \text{ and } V < V_{11}$$

the system switches to the equilibrium glide mode.

During the equilibrium glide regime, the command parameter is (L/D) not \dot{h}_C . This command is computed from the equation:

$$(L/D)_C = (L/D)_{NOM} + \frac{K}{R_o} \left[\frac{D_{go_i} - D_{SG_i}}{\ln \left(\frac{1}{1 - \frac{(V_i)^2}{(V_o)^2}} \right)} \right] \quad (17)$$

where

$$D_{SG_i} = 1/2 R_o (L/D)_{NOM} \ln \left[\frac{1}{1 - \frac{(V_i)^2}{(V_o)^2}} \right] + h_s (L/D)_{NOM} \ln \left[\frac{(V_i)^2 C_{DS}}{\rho_F 2 a_i} \right] \quad (18)$$

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With ρ_f being the air density at the recovery interface. Lateral control is obtained by switching the bank sign when:

$$|D_{Ce}| \leq K_L (V_i)^2 \quad (19)$$

This results in a sequence of "S" turns whose magnitude goes to zero with velocity. The term K_L is selected so that twice the cross range error can be corrected at the velocity V_i . Guidance is terminated with drogue chute deployment.

The equations establishing the deployment conditions are not presently known, but it is assumed they will involve simple functions of such parameters as velocity, dynamic pressure and/or Mach number.

The digital computer will essentially provide a functional simulation of the Apollo Guidance Computer, insofar as the solution of the above equations is concerned. Scaling and solution rates will be similar to that of the Apollo computer, however, the transmission formats and data handling techniques (used in the trainer computer complex) will reflect the greater capability of the computer complex.

This simulation of the automatic guidance mode is necessary to provide the following:

1. Training in recognition of malfunctions during this phase.
2. Training in making an important decision (whether to switch to manual control or not)
3. Automatic setup of initial conditions for manual control mode, so that switch-over from automatic mode to manual mode may be made at any time.
4. Training in monitoring performance during automatic mode.

Reentry Guidance (Backup)

The primary function of the crew during the automatic flight mode of the reentry phase will be to monitor the automatic system. They will, however, have the capability at any time to override the system to take over manual control. In the event of system failure, therefore, some capability will still exist to "fly" the vehicle. A very important training aspect will therefore be to introduce subsystem malfunctions to force the use of manual control. The introduction of such malfunctions will thus be part of the

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training program. The principal instrument to be employed in the back-up mode is an acceleration history display, a typical example of which is shown in Figure 13. The two heavy lines define the corridor boundaries and the line between them shows the reference trajectory within the corridor boundaries.

The entry display, which is also used as a monitor, is operational during all reentry regimes, normal or manual. No additional computations are required for the back-up guidance, which is initiated by the opening of the automatic control (see Figure 14). At the instructors' console an indicator will be located above the reentry display and will be illuminated in the event of skip-out; the mission will then be terminated.

The most critical parameter in the reentry problem is the reentry angle, so it is natural that the training situation develop on variations of the entry angle for specified initial position. This will provide training over a large class of entry trajectories. Additional training procedure will incorporate statistical deviations on the vehicle coordinate values, (i.e., on the initial state vector) so as to simulate measurable errors in the inertial guidance system at entry.

The degree of difficulty of the manual control function will vary with the kind and the extent of the subsystem malfunctions. In particular, a loss of control of yaw and pitch rate could produce a great deal of difficulty because the lift characteristics would cease to be a relatively simple function of roll angle. Intensive training in this area could, however, reduce the difficulty considerably. Simulated malfunctions in the pitch and yaw rate damping channels will be provided.

Dynamic simulation of the altitude control loops and vehicle aerodynamics in the analog computer provides a wide range of training capability. In particular, the effects of simulated malfunctions may be allowed to propagate through the system, just as they would do in the actual situation.

No provision is being made in the trainer for reentry guidance assistance from ground support sources, since this will probably not be available.

EXTRA-ATMOSPHERIC PHASES

In this section mechanization equations for the extra-atmospheric mission phases are presented. The training missions in these phases are not continuous over an entire phase, but rather consist of relatively brief segments (in time). This is one major difference between the atmospheric and extra-atmospheric training missions. Another major difference is

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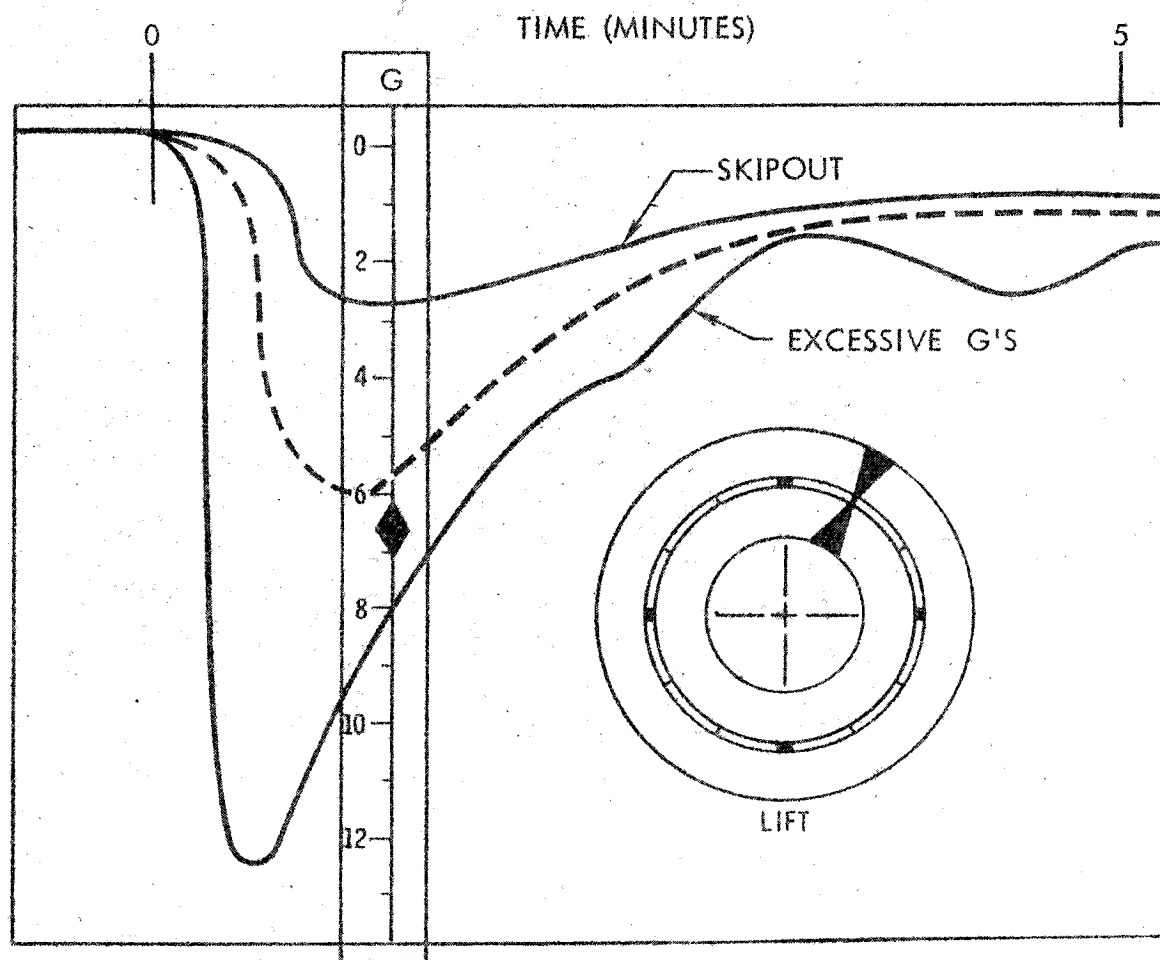
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Figure 13. Entry Display

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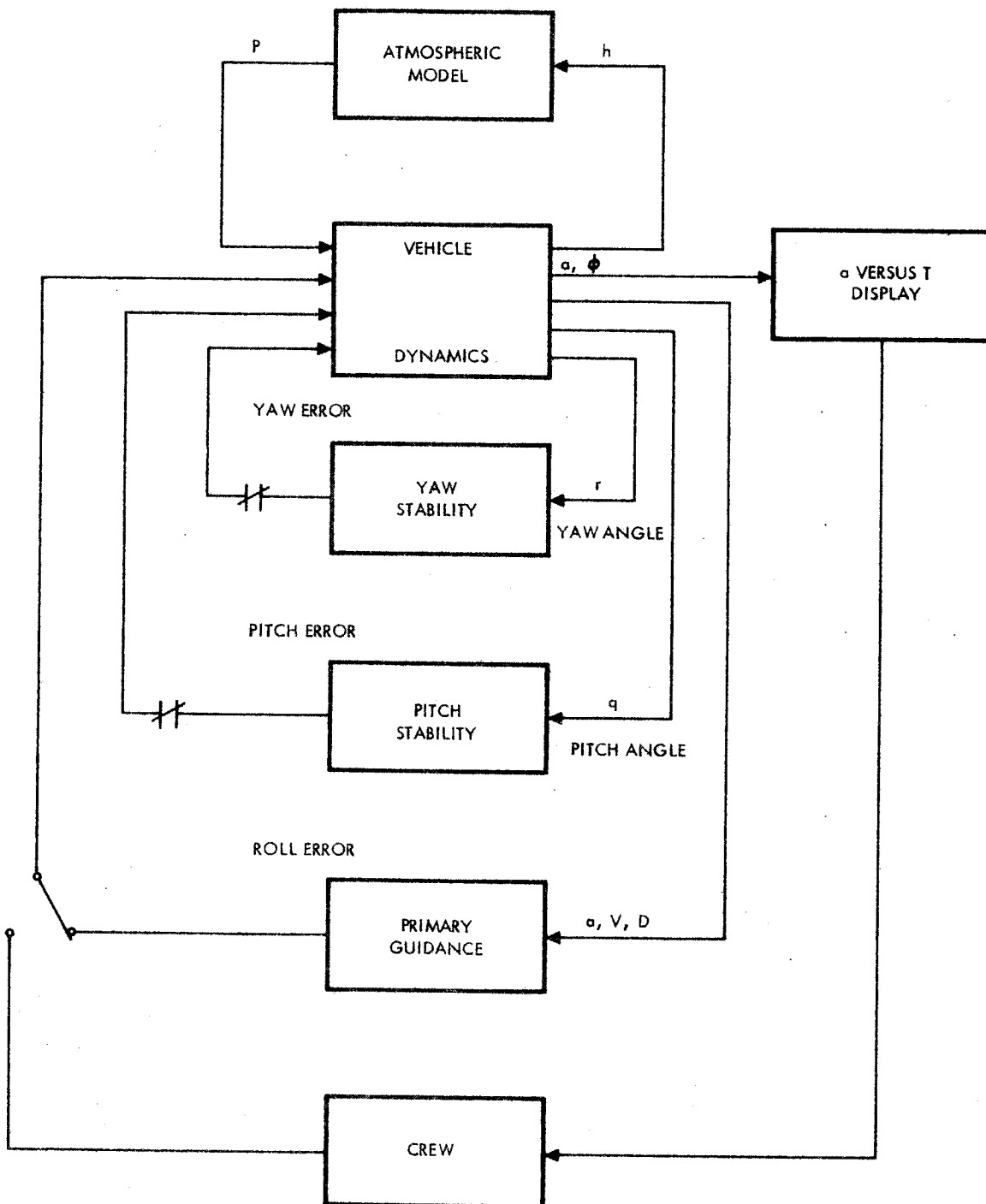
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Figure 14. Vehicle Dynamics and Guidance Simulation Block Diagram

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in the mechanization of the equations of motion. During the atmospheric phases the translational equations of motion are in the guidance and control loop, while in the extra-atmospheric phases, these equations are not part of any closed loop. The rotational equations of motion will be solved in closed loop fashion in all phases, because of the requirement that vehicle attitude dynamics be simulated.

Earth Orbit

The rotational equations of motion will be solved on the analog computer; and SCS system dynamics will be simulated in the analog computer. Position and velocity will be obtained from data stored in the digital computer prior to initiation of the training mission. The data will be in the form of standard orbital parameters; it will be assumed that the orbit is circular. Position and velocity are readily computed from this data.

Define a set of axes $X_c Y_c Z_c$ such that $X_c Y_c$ lie in the orbital plane with the X_c axis passing through the ascending node and the Z_c axis completing the righthanded system (see Figure 15). Let the matrix that carries $X_s Y_s Z_s$ into $X_c Y_c Z_c$ be denoted by B :

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix} = [B] \begin{bmatrix} X_s \\ Y_s \\ Z_s \end{bmatrix} \quad (1)$$

then:

$$X_c^2 + Y_c^2 = R^2 = \text{constant}$$

$$\dot{X}_c^2 + \dot{Y}_c^2 = V^2 = \frac{\mu E}{R} = \text{constant}$$

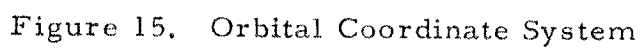
$$\bar{V} = \bar{W} \times \bar{R}$$

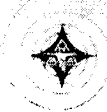
$$\dot{X}_c = -WR \sin \omega (t - T)$$

$$\dot{Y}_c = WR \cos \omega (t - T)$$

$$[B] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos i & \sin i \\ 0 & -\sin i & \cos i \end{bmatrix} \begin{bmatrix} \cos \Omega & \sin \Omega & 0 \\ -\sin \Omega & \cos \Omega & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (2)$$

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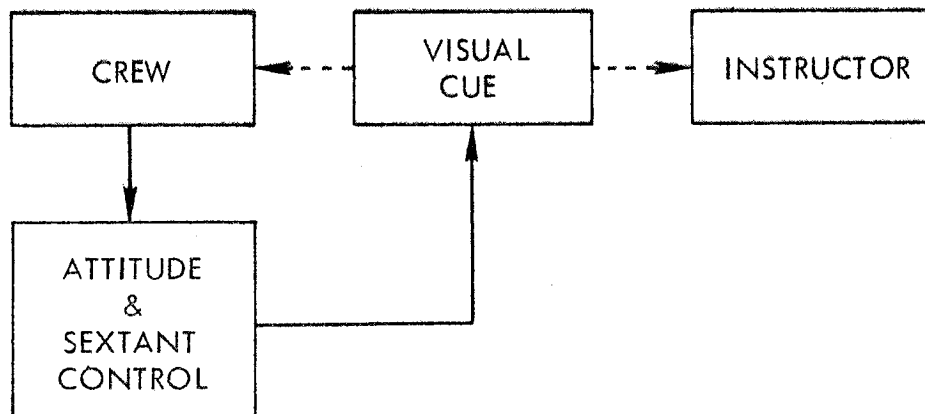
The required orbital parameters are i (inclination), R (orbital radius), Ω (longitude of ascending node) and T (time of passing through ascending node). Position and velocity components would be computed according to equations (2) and transformed to the S system using the inverse of (B) . Note that Ω and i define the rotational matrix (B) .

Position and velocity relative to the (moving) earth may be obtained using the relations given on page 49. The rotational equations of motion are:

$$\begin{bmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix} = [I]^{-1} \left\{ \begin{bmatrix} \Delta L \\ \Delta M \\ \Delta N \end{bmatrix} - \begin{bmatrix} 0 & -r & q \\ r & 0 & -p \\ -q & p & 0 \end{bmatrix} [I] \begin{bmatrix} p \\ q \\ r \end{bmatrix} \right\} \quad (3)$$

It is assumed that the elements of I , the moment of inertia matrix, are all constant. As noted earlier, these equations will be solved on the analog computer. The outputs of the analog computer will be used to drive the attitude displays and will also tie into the visual cue system.

Information flow for visual system tie-in is indicated below.



The visual cue is required for training in platform alignment procedures. Absolute accuracy is not required for this procedural training, but dynamic response of attitude control loops must be simulated to give the crew members training in the sextant alignment operation. The analog

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computer will be used to simulate attitude dynamics and to drive the visual cue display as determined by the crew member's input and this dynamic response. The detailed mechanization equations relating attitude and sextant angles are being investigated.

Mid-Course Phase

The mid-course phase training will emphasize procedures rather than accuracy, as in the earth orbit phase. Training missions will consist of "short" (in time) segments of the mid-course phase. Procedural training will be provided in:

1. platform alignment
2. star-landmark fixes
3. ΔV corrections
4. injection into trans-lunar and trans-earth trajectories, and injection into lunar orbit

Item (1) has been discussed above; item (2) is similar insofar as mechanization equations are concerned, except that additional digital (AGC) displays will be provided.

The last two items both involve platform alignment as part of the procedure; this will be included in the particular training mission segment, or left out, at the option of the instructor. The digital displays required for communication with GOSS (the instructor) will be part of the stored program, and will be displayed as called up by the crew. It is estimated that only 100 to 200 words will be required for such displays, because of the shortness of the mission segment. Such readouts will include angular measurements and deviations, and velocity corrections (magnitude and direction).

Position and velocity information for display purposes will be generated from trajectory data stored in the digital computer prior to initiation of the training mission. The method used will be similar in principle to that used for the launch and earth orbit mission phases. This method eliminates the need to store many data points, and permits call-up at any time.

Midcourse ΔV corrections will be programmed into the computer prior to initiating the run, or will be inserted by the instructor. These simulated corrections will not be related to the angular readings made by the crew; they will be provided for procedural training in the ΔV correction maneuver.

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Injection into trans-lunar trajectory will be based on a simplified version of the off-set target scheme. A correlated velocity (or required velocity) will be calculated on the basis of a two-body problem:

$$V_c^2 = \frac{\mu_E V^2 (R \cdot R_T - \bar{R} \cdot \bar{R}_T)}{R (\bar{R} - \bar{R}_T) \cdot [V^2 \bar{R} - (\bar{R} \cdot \bar{V}) \bar{V}]} \quad (4)$$

which is the standard "hit equation." One additional condition must be imposed for control purposes. This additional constraint is imposed by requiring the time of flight to be a constant. This condition may be translated into a corresponding condition on γ (angle between \bar{R} and \bar{V}):

$$0 = dt_f = \frac{\partial t_f}{\partial V} dV + \frac{\partial t_f}{\partial \gamma} d\gamma \quad (5)$$

Or:

$$d\gamma = - \left(\frac{\frac{\partial t_f}{\partial V}}{\frac{\partial t_f}{\partial \gamma}} \right) dV \quad (6)$$

The coefficient of dV is a precomputed number. The correlated velocity is related to the velocity to be gained.

$$\bar{V}_g = \bar{V}_c - \bar{V} \quad (7)$$

From equations (4) and (6)

$$\begin{aligned} \bar{V}_g &= (V_c - V) \bar{l}_v + V d\gamma \bar{l}_n \\ &= V_c \bar{l}_v + V d\gamma \bar{l}_n - \bar{V} \end{aligned} \quad (8)$$

Which follows also by analogy from

$$d\bar{V} = d(V \bar{l}_v) = dV \bar{l}_v + V d\bar{l}_v = dV \bar{l}_v + V d\gamma \bar{l}_n \quad (9)$$

Steering signals to control the attitude displays would be similar to that described in section on orbital injection.

Lunar orbit injection would be similar to earth orbit injection. Mechanization of the injection into trans-earth trajectory would be similar to the trans-lunar injection mechanization described above.

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V. DESCRIPTION OF TRAINER COMPLEX

COMPUTER COMPLEX

To fulfill the requirements for procedures training and attitude control, a digital-analog hybrid computer system will be used. The computer system will include a digital computer, plus its peripheral equipment, an analog computer, and all necessary hardware, software, and interface configurations required to implement the trainer's objectives. Figure 16 shows a block diagram of the digital and analog equipment.

The digital computer will generate displays and control the analog computer. Generally, digital computations will be done in real time. The analog computer will solve the rotational equations of motion and provide the dynamic response of the stabilization and control system.

Digital Computer

The digital computer's major tasks will be to: (1) provide displays (precomputed or canned information) for procedures training, (2) monitor and control the analog computer, (3) execute functions such as the control program, malfunction control, on-line diagnostic check, and real time input/output, and (4) compute trajectory data.

The digital computer will incorporate, in conjunction with the main control program, several sub-programs. The launch abort sub-program will contain all necessary mathematics to simulate either an atmospheric or an extra-atmospheric mission termination.

All calculations in both the abort and reentry sub-program will be done in real time. Upon receipt of input from the instructors' console, the executive control sub-program directs the computer complex in the solution of the problem. The program accomplishes this by controlling the flow of data between the various components throughout the computer complex.

Desired malfunctions may be introduced through either preprogramming prior to initiating the mission or by a command from the instructors' console during the mission.

In order to perform the aforementioned computations, a central processing unit with a core storage of 8K 24 bit words will be required. Table 3 presents a breakdown on the allocation of digital computer core storage for instructions and data words required for the Apollo Part Task Trainer.

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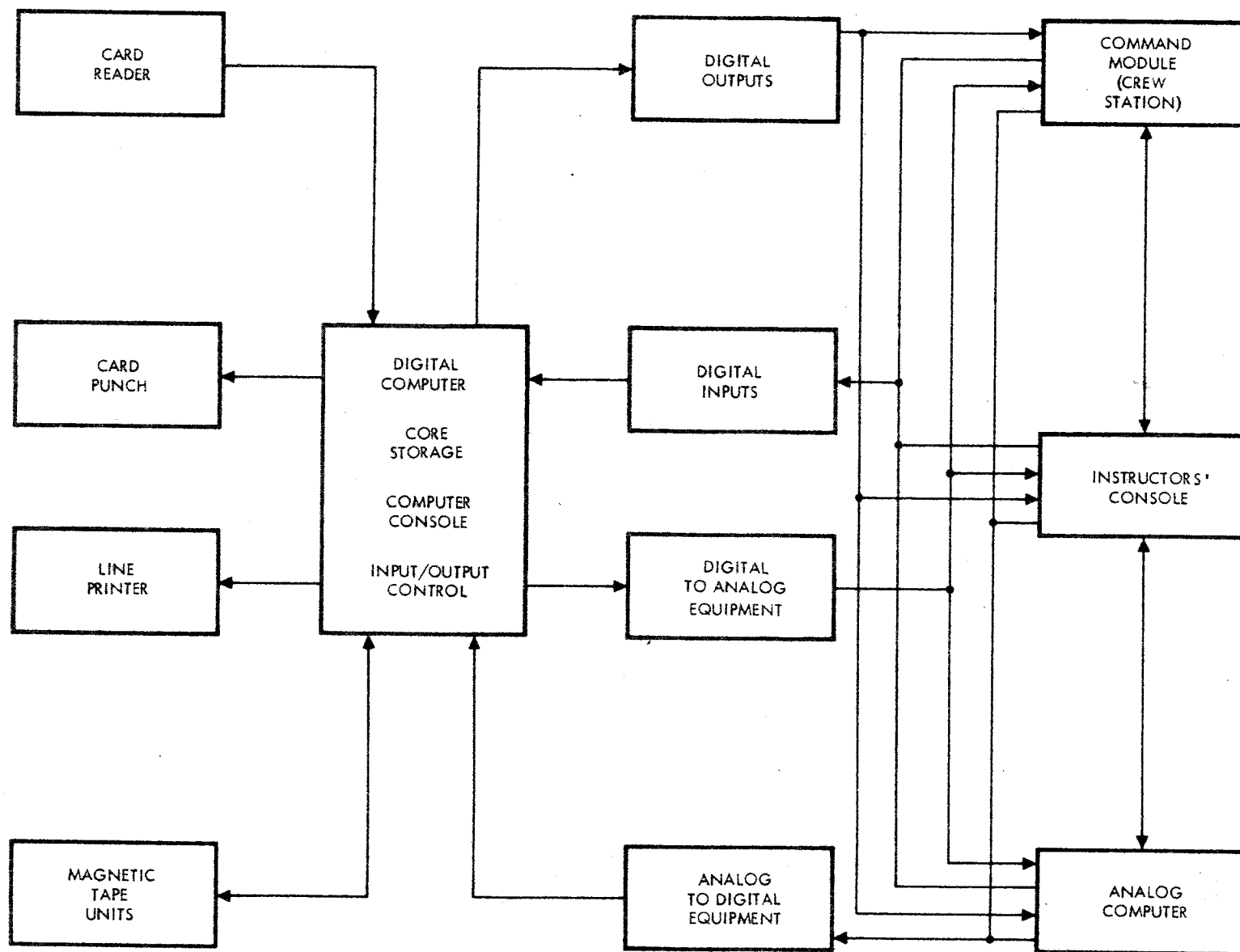


Figure 16. Digital and Analog Equipment Block Diagram

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Table 3. Digital Computer Instructions and Data Estimate

Description	Instructions	Data
Control program	1000	500
On-line diagnostics	1000	500
Input/output	500	250
Precomputed trajectory and attitude displays	1500	1500
	—	—
Subtotal	4000	2750
	2750	
	—	
TOTAL	6750	
Note: Estimated maximum number of instructions per iteration = 4000		

Input/Output Equipment

The digital computer input/output equipment required is divided into two categories: (1) standard peripheral equipment, (2) digital to analog (D/A) and analog to digital (A/D) conversion equipment.

Standard Peripheral Equipment

1. Card Reader
2. Card Punch
3. Line Printer
4. Magnetic Tape Units
5. Control Units as required for the above equipment. (The nature and number of these units will depend on the particular digital computer selected.)

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These peripheral devices are required for the storage of operational and diagnostic programs, the storage of data, the de-bugging of new programs, and the maintenance of the computing equipment.

There will be two types of stored data: (1) the data required for the real time computations that will be performed during the abort and reentry phases, and (2) precomputed, or "canned" information used in the simulation of fixed trajectories and other predetermined conditions.

The card reader, card punch, and line printer may be relatively slow speed devices. The magnetic tape units will be of medium to high character recording density for transferring the anticipated volume of "canned" information from the magnetic tape units to core storage and subsequently to the analog equipment.

D/A and A/D Conversion Equipment

The D/A equipment is required for converting information from digital form to analog form to drive such devices as meters and to supply analog signals to the analog computer. It will consist of the logic required for selecting the proper output lines (particularly meters, etc., to be updated), conversion from digital to analog signals and storing or "holding" this information until the next update occurs.

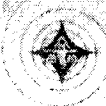
The A/D equipment performs the reverse function, namely, converting information from an analog to a digital computer. It will consist of the logic for selecting the proper input lines, and conversion from analog to digital signals.

Digital Inputs and Outputs

There are an additional number of inputs and outputs that require processing by the digital computer. These inputs and outputs are digital in nature and are necessary to simulate such functions as relay closure inputs, binary coded inputs, indicator lamp outputs, and switch closure inputs.

Analog Computer

In this section the analog computer problem load is discussed, and the equipment required is listed.

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Analog Computer and Problem Load

The rotational equations of motion will be mechanized on the analog computer. These equations, referenced to the vehicle's body axes, are of the form:

$$\dot{p}I_x - \dot{r}I_{xz} = C_l Q + T_x$$

$$\dot{q}I_y = C_m Q + T_y$$

$$\dot{r}I_z - \dot{p}I_{xz} = C_n Q + T_z$$

They were described on pages 63 and 65.

In addition to solving the above equations, the analog computer will be used to simulate the stabilization and control system and the propulsion systems. For the launch and reentry cases only partial mechanization of the stabilization and control system is required. The operational modes are (1) monitor (during launch), (2) SCS entry and guidance, and (3) navigation entry.

Included in the SCS is the reaction logic. Reaction jet fuel consumption will be computed using the equation:

$$W_F = \frac{F_C}{I_{sp}} \int_0^{t_c} dt$$

where:

W_F is the reaction jet fuel weight in pounds

F_C is the reaction jet thrust in pounds

I_{sp} is the specific impulse in pounds of thrust per pound per second of fuel (seconds)

t_c is the reaction jet on time in seconds

Roll will be unlimited (0 to 360 degrees); yaw and pitch will be limited during reentry to plus or minus 50 degrees from the equilibrium position. During orbit and midcourse phases roll, pitch, and yaw will be unlimited.

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Equipment

The problem load described essentially determines the amount of analog computing equipment required, because the SCS mechanization for the extra-atmospheric phases (earth orbit and mid-course) is less complex than that required for the atmospheric phases (launch and reentry). Equipment required by the analog section to mechanize the problem load are given in Table 4.

Table 4. Analog Equipment Required for Mechanization of Problem Load

Item	Quantity	Description
1	1	Control console with associated controls, readouts, displays, etc.
2	100	Manual 2-terminal coefficient potentiometers
3	15	Dual feedback limiters
4	175	Operational Amplifier 45 summer integrators 130 summers and inverters
5	30	Electronic quarter square multipliers
6	10	Resolvers
7	4	Variable function generator
8	100	"AND" gates to perform the jet selection
9	45	Digital to analog switches to convert the jet pulse to analog signals

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TRAINER COMMAND MODULE

The trainer command module will physically approximate the inner shell of the actual Apollo spacecraft command module, and be a fixed base type trainer (see Figure 17). The interior crew compartment of the trainer command module will be a near duplication of the spacecraft command module interior. Crew stations will be provided within the crew compartment for the three man crew. These stations are identified as:

1. Control station (L. H. couch)
2. Center station (center couch)
3. Systems management station (R. H. couch)
4. Navigation station (accessible when center couch is stowed)

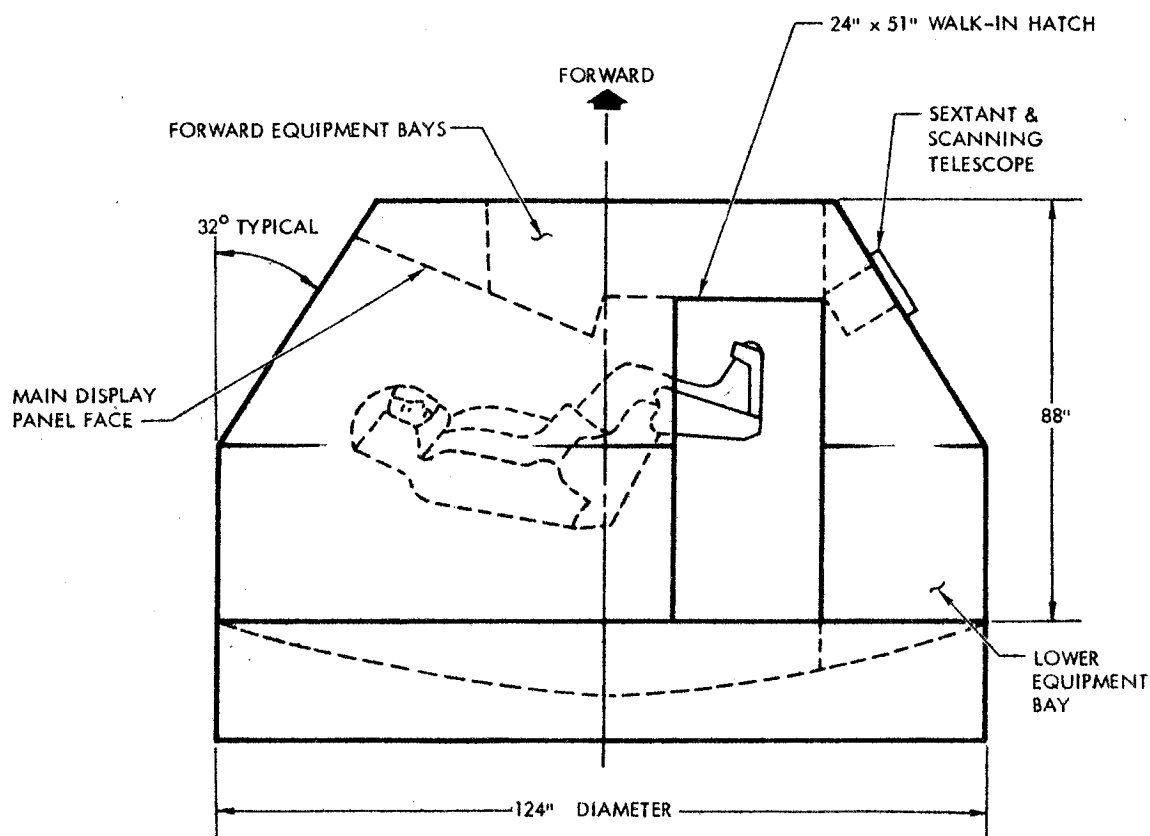
The crew compartment will house three couches with spacecraft adjustment and stowage capabilities and their suspension system. The main display panel, the guidance and navigation display panels, the right hand and left hand consoles and all other associated displays and controls required will also be located within the crew compartment. The trainer command module will contain equipment bays deployed in their respective locations (see Figures 17 and 18).

Ingress and egress hatches will be provided as follows (see Figures 17 and 18):

1. The normal center window hatch.
2. A 24" x 51" walk-in hatch through the R. H. equipment bay.
3. An emergency 30-inch-diameter hatch at the top.

The windows of the trainer command module will have simulated window hatches with crew operable opening and closing window hatch controls.

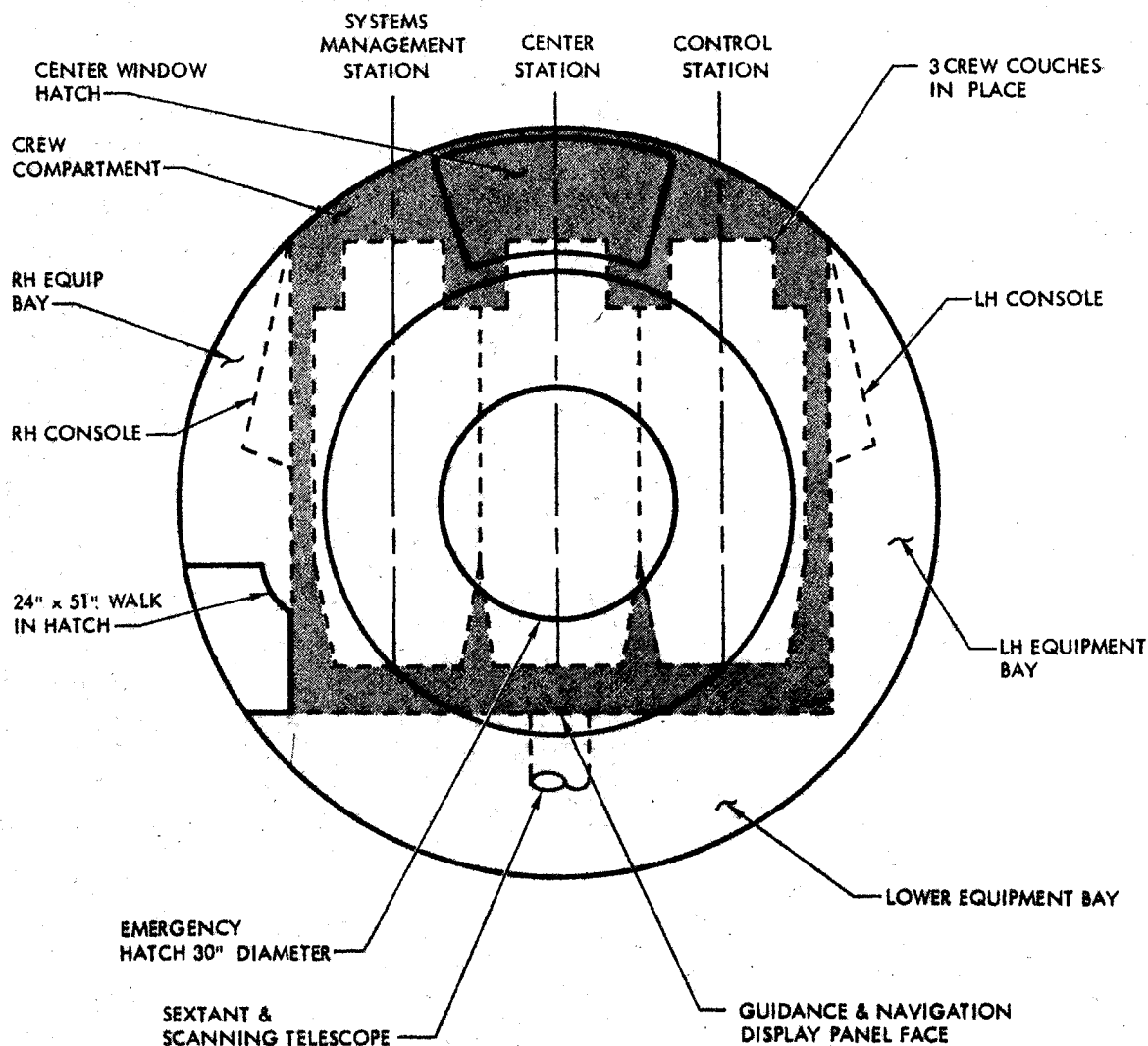
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NOTE: ALL DIMENSIONS ARE APPROXIMATE

Figure 17. Trainer Command Module: Elevation

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NOTE: WINDOWS NOT SHOWN

Figure 18. Trainer Command Module: Top View

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Controls and Displays

Controls and displays will be provided as required to permit the crew to control the simulator and monitor the parameters essential to an acceptable mission performance.

Main Display Panel

The main display panel (see Figure 3) will be positioned above the heads of the three crew couches in the trainer command module. It will incorporate the displays and controls for the three operator stations.

Control Station. The control station will be composed of the main display panel area positioned above the control station operator's couch. The station will contain the following displays and controls.

1. Barometric indicator
2. Event time indicators (2)
3. Integrated display panel
4. Abort indicator
5. Gimbal position indicator
6. SCS control panel
7. Flight director attitude
8. Indicator
9. Rendezvous display
10. ΔV display panel
11. Entry monitoring indicator
12. Master caution indicator group
13. Computer keyboard and readout
14. Display
15. GMT clock

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Center Station. The Center Station will be composed of the main display panel area positioned above the center station operator's couch. The station will contain the following displays and controls.

1. Service propulsion display panel
2. Reaction control display panel
3. Abort indicator
4. SCS power control panel
5. Service module quadrant temperature indicator
6. Audio control panel
7. IFTS scan select panel
8. Booster situation indicator
9. ECS (liquid) display panel
10. ECS (gas) display panel
11. Warning indicator groups (2)

System Management Station. The systems management station will be composed of the main display panel area positioned above the systems management station operator's couch. The station will contain the following displays and controls.

1. Electrical power distribution display No. 1
2. Electrical power distribution display No. 2
3. Electrical power distribution display No. 3
4. Master caution indicator group
5. Fuel cells display panel
6. Cryogenic display panel

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7. Abort indicator
8. Telecommunication control panel
9. Antenna control display panel
10. Eight day clock

Hand Controllers

Provision to accomodate demountable hand controllers will be incorporated in the armrests of the control station operator's couch and the center station operator's couch. The controllers will consist of 1 three-axis attitude controller and 1 three-axis translation controller for each station. When in use, the attitude controller will be mounted to the right armrest of each couch and the translation controller to the left armrest. Provision will be made for stowage of the controllers when not in use.

Lefthand Console

The lefthand console will be located to the left of the main display panel and will be accessible to the control station operator. The console will contain the following displays and controls.

1. Earth landing control panel
2. Vent valve control panel
3. Lighting control panel
4. Separation control panel
5. Audio control panel
6. Circuit breaker panel

Righthand Console

The righthand console will be located to the right of the main display panel and will be accessible to the systems management station operator. The console shall contain the following displays and controls.

1. Radiation indicator display panel
2. Lighting control panel

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3. Audio control panel
4. Circuit breaker panel

Navigation Station

The navigation station will be located in the lower equipment bay, positioned to provide optimum operator access when center couch is stowed. The station will contain the following display and controls.

1. Optical measuring unit controls and viewing access
2. Automatic guidance equipment displays and controls
3. Abort indicator
4. Master caution indicator group
5. Panel display lighting controls
6. Computer keyboard and readout display

The navigation station will incorporate provisions to mount 1 three-axis attitude controller. The display and control panels are shown in Figure 19.

INSTRUCTORS' STATION

The instructors' console will consist of all necessary equipment of a monitoring, recording, or control nature sufficient to insure accomplishment of the part task training mission

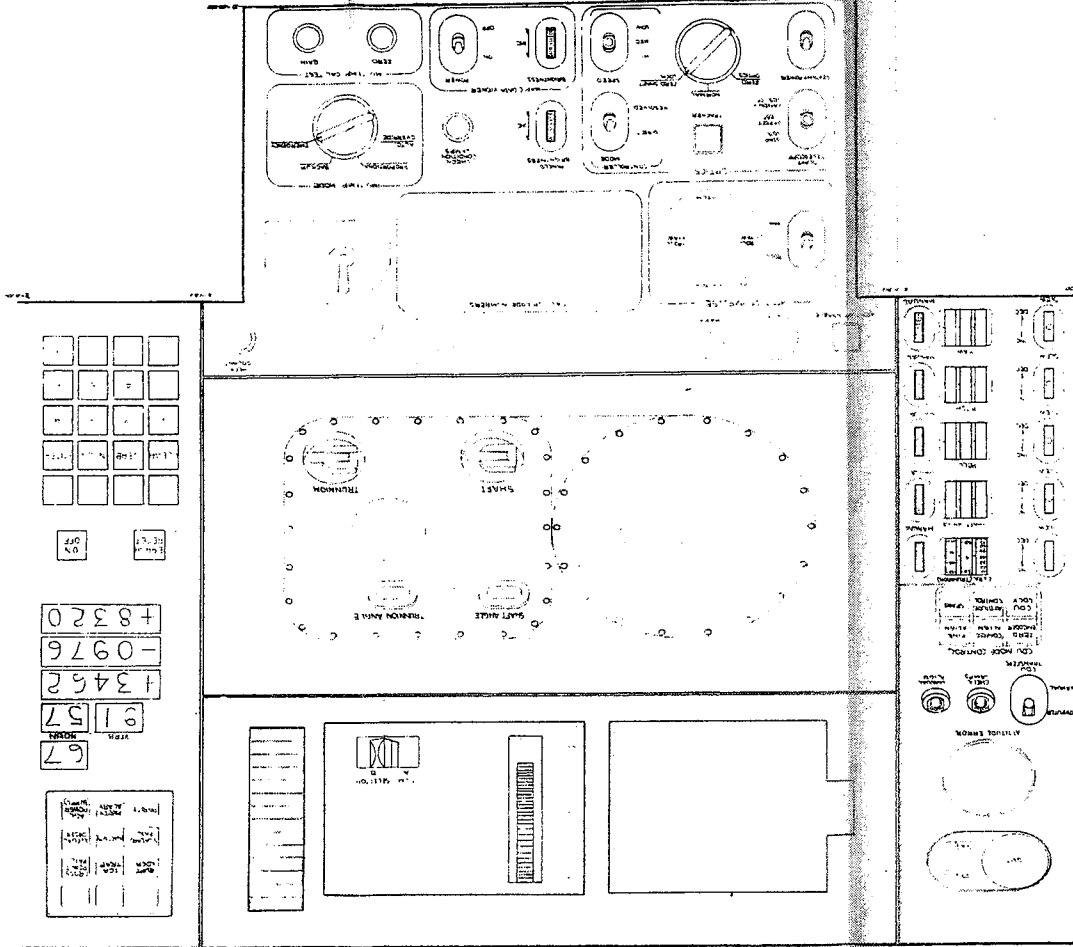
Information normally observed or controlled by the crew in the trainer command module will be additionally displayed at the instructors' station. This includes duplication of all active crew station displays, switch positions, control settings, indicators, and any other information pertinent to trainer operation.

The trainer shall have an override communications loop and facilities for mating to a GFE call director system (see Figure 20). The call directors shall be supplied as GFE and shall include the equipment required to complement the system such as headsets and amplifiers. Mounting space shall be provided for installation of call director equipment. The override communications loop will provide for communications between the crew station and instructors' station in the event of failure in the GFE switching equipment.

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Figure 19. Guidance and Navigation Display: Lower Equipment Bay



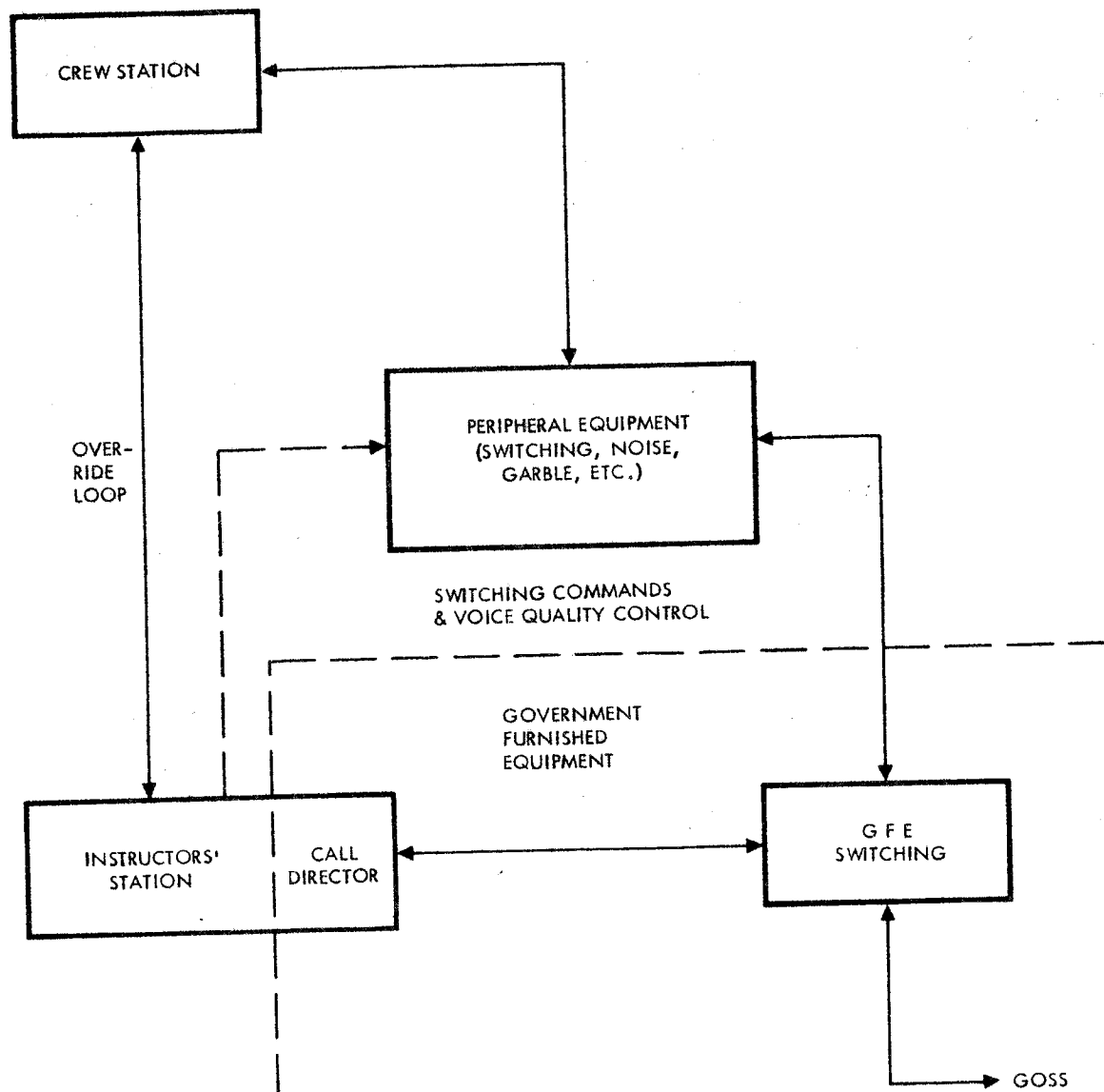
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Figure 20. Communications Block Diagram

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Instructor control of communication will allow command control of conversation with the crew. The instructor will be able to simulate all GOSS functions.

Malfunctions and instructor-controlled variables will be accomplished or ordered by the instructor. The instructor control station will monitor and control the training program, providing alterations in this program for the crew. Actively simulated systems within the trainer Command Module crew stations will be under instructor monitor and control. Controls of the training problem will be effected as follows.

1. Malfunction insertion
2. Switch-controlled inputs exercised by the instructor
3. Variable controls operated by the instructor

Displays

The upper portion of the instructors' console face will comprise repeater displays of all main display panel instruments and control setting information available to the crew. Adjacent side consoles of the instructors' station will contain repeater navigation station and other displays pertinent to the part task trainer. The instruments will be associated functionally similar to the instrument arrangement of the Apollo Command Module. The equivalent display of the crew instrument display will allow ease in viewing read-out quantities as observed from the respective instructor's position.

All controls requiring manipulation by the instructor will be located near the simulated instrument panel display (see Figure 4).

TRAINER COMPLEX HARDWARE MECHANIZATION AND INTEGRATION

The tabulation in Appendix C represents the approach to trainer subsystem hardware integration in accordance with the philosophy established in preceeding portions of this report. The listing outlines and defines signal flow (functional) between the computer complex, crew station, and Instructors' station, with a description of all panel parameters to be mechanized, including the extent of mechanization. A functional diagram of the trainer complex prepared from the listing will act as the basis for initiation of detailed design.

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APPENDIX A

PRELIMINARY INSTRUCTOR AND TRAINING-TIME REQUIREMENTS

Instructor and training-time requirements are listed in Table A-1. At least two instructors are required for every training operation or session. A maximum of three instructors is required for training in any one of the listed operations. The data submitted in this table is provided for the recommended formal training schedules. An "X" in the table indicates that formal training will not be attempted for the positions indicated in the column heading.

Informal training schedules may be instigated at the option of the using agency. It is anticipated that at least one instructor will be required during any informal training session. Further study will more accurately determine the instructor tasks required and, therefore, the number of instructors needed per training session. This will be undertaken when more complete data becomes available.

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Table A-1. Instructor and Training-Time Requirements

Operations	Time (min)	Positions Occupied				Number of Instructors Required
		LH	LH & C	LH & RH	LH, C, & RH	
Prelaunch setup and checkout	30	X	X	3	3	
Final countdown	20	X	X	3	3	
Ascent	9	X	X	3	3	
Earth orbit evaluation	53	2	2	2	3	
Translunar injection	21	2	2	2	3	
Systems and trajectory checkout I	18	2	X	2	3	
Midcourse correction I	139	2	3	3	3	
Lunar orbit injection	115	2	2 or 3	2 or 3	3	
Lunar orbit evaluation	100	2	2 or 3	2 or 3	3	
Transearth injection	61	2	2	2	3	
Systems and trajectory checkout II	90	2	2	2	3	
Midcourse correction II	94	2	3	3	3	
Prepare for earth entry	60	2	2	2	3	
Earth entry	15	2	2	2	3	

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APPENDIX B

APOLLO SUBSYSTEMS DESCRIPTION

The systems descriptions contained in this appendix are based on information available at the time of writing. Systems changes which occur in the future will be revised accordingly.

All system displays and controls applicable to the Apollo Part Task Trainer will be simulated to represent those in the actual Command Module. The operation of the various controls will effect applicable displays just as they would under actual operating conditions. Actual displays and controls, modified as required for training purposes, will be used where maximum effectiveness of training will result. Displays and controls not applicable to the training requirements will be realistically mocked up.

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STABILIZATION AND CONTROL SYSTEM (SCS)

SYSTEM DESCRIPTION

The major functions of the stabilization and control system are:

1. Secondary inertial reference
2. Attitude rate
3. Thrust vector control
4. Manual control

This system includes the sensors, controls, logic networks, displays, and output devices required for controlling the attitude and motion of the Apollo spacecraft. The stabilization and control system has several modes of operation. Depending on the mission phase, these modes can be selected at crew option. In operation the SCS receives commands from the guidance and navigation system or crew input and causes the dynamics of the spacecraft to respond to those commands. Thus, in presenting the SCS, the spacecraft body dynamics must be considered as an integral part of the control loops. The SCS in conjunction with the deep space instrumentation facility (DSIF), provides a manual control function for the safe return of the spacecraft, in the event of a failure in the guidance and navigation system. There are no requirements on the SCS during the landing phase of the mission. Therefore, as the descending spacecraft reaches approximately 25,000 ft, signals from a baroswitch in the earth landing system jettisons the forward heat shield of the Command Module and deactivates the SCS. Figure B-1 is a block diagram of a simulated stabilization and control system.

Displays and Controls

The following display and control functions are provided by the stabilization and control system:

1. Control mode selection (8 modes)
2. Attitude deadband adjustment (roll, pitch, yaw)
3. Channel disable command (roll, pitch, yaw)

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4. Attitude indication (roll, pitch, yaw)
5. Attitude error indication (roll, pitch, yaw)
6. Body rate indication (roll, pitch, yaw)
7. Attitude command (roll, pitch, yaw)
8. Translation command (X, Y, Z)
9. Engine gimbal angle indication (pitch, yaw)
10. Engine gimbal position command (pitch, yaw)
11. Emergency ullage fire command
12. Main engine fire command and operation
13. Main engine cutoff command and operation
14. ΔV required command (magnitude set)
15. ΔV remaining indication
16. System power ON-OFF command
17. Rate gyros power control mode select (3 modes)
18. Attitude gyros power control mode select (3 modes)

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GUIDANCE AND NAVIGATION SYSTEM (G&NS)

SYSTEM DESCRIPTION

The guidance and navigation system performs the semiautomatic calculations of spacecraft position, velocity, attitude, and trajectory and provides control signals to the stabilization and control system to alter or correct these parameters to successfully guide the spacecraft through the various mission phases from earth orbit to earth reentry and landing. The G&NS is composed of the following major components.

1. Inertial measurement unit
2. Apollo guidance computer
3. Coupling display unit
4. Scanning telescope
5. Sextant
6. G&N displays and controls
7. Rendezvous radar
8. Optical beacon

The on-board system is backed up by the ground operational support system (GOSS). A block diagram of a simulated system is shown in Figure B-2. For displays and controls see Figure 19.

Displays and Controls

Displays and controls located at or adjacent to the navigator's station

1. Computer group
 - a. Keyboard
 - b. Call up variables (nixie lights)
 - c. Conditional lights

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E-11, P-12

STD 62-1434

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- d. Program selector
 - e. Print out control
 - f. Keyboard tape selector
2. Sextant and scanning telescope group
- a. Mode selector
 - b. Two-axis pencil stick controller for optics
 - c. Precision-axis pencil stick controller
 - d. Speed selector for optics control stick
 - e. Computer-manual drive selector
 - f. Computer "mark" button
 - g. Sextant line of sight selector
 - h. Cranks for manually positioning scanning telescope
 - i. Scanning telescope shaft and trunnion angle display
 - j. Sextant shaft angle indicator
 - k. Sextant optical bridge
 - l. Tracker connector for sextant automatic tracking eyepiece
 - m. Backup bellows pump handle
 - n. Attitude roll-rate control stick
 - o. Attitude disable control
 - p. Single impulse control for roll attitude
3. Inertial measuring unit group
- a. PSA control and IMU heater
 - b. Temperature indicator

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- c. Temperature selector
- d. Thrust accelerometer controls
- 4. Coupling display unit group
 - a. Computer-manual selector
 - b. Mode selector
 - c. CDU angle readout
 - d. Speed controls
 - e. Attitude error display
- 5. Gyro-torquer group
 - a. Gyro selector
 - b. Polarity selector
 - c. Speed selector
- 6. Printer
- 7. Instruction template
- 8. Clock group
 - a. GMT clock
 - b. Film strip selector
 - c. Manual film advance control
 - d. Film frame counter
 - e. Film storage
- 9. G&N power controls
- 10. Conditional, caution, and abort lights

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Main display panel

1. Computer group
 - a. Keyboard
 - b. Call up variables
 - c. Computer conditional lights
 - d. Program selector
2. Radar group
 - a. Doppler velocity
 - b. Radar altitude
 - c. Tracking radar
3. Attitude error signals
4. IMU gimbal angles display
5. Viewer
6. G&N conditional lights and controls

Presentation of Navigation and Flight Procedure Information

A display will be provided which is capable of visual presentation of recorded information as required for isolated part task training including:

1. Navigation charts and maps
2. Guidance computer operating procedures
3. Flight procedure (checklist) information
4. Computational aids for CG management
5. Computational aids for presetting of flight controls

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PROPULSION SYSTEMS

SYSTEM DESCRIPTION

The crew is required to monitor and control propulsion systems during all phases of a mission. These systems are:

1. Service propulsion system (SPS)
2. Reaction control system - Service Module (RCS-S/M)
3. Reaction control system - Command Module (RCS-C/M)

Service Propulsion System (SPS)

The service propulsion system provides propulsion for orbital correction, rendezvous maneuvers, midcourse velocity corrections (ΔV), post atmospheric aborts, and retrograde thrust from an earth orbital mission. The service propulsion rocket engine utilizing liquid propellants is a non-throttleable engine. The engine is gimballed to provide vehicle stabilization and control. Operation of the gimbal actuators is controlled by commands from the stabilization and control system (SCS) with an override provision for crew operation.

The Service Module propulsion propellant feed system provides for fuel and oxidizer storage and a pressurization system for propellant tanks.

The system functions automatically by means of electrical inputs which sequence the system operation. Displays for the purpose of monitoring system functions and controls providing manual override capability are located on the service propulsion control panel in the Command Module.

Reaction Control System - Service Module (RCS-S/M)

The service reaction control system provides the impulses for attitude control and stabilization for the space vehicle in all phases of flight except on earth launch prior to earth parking orbit. The system also supplies retrograde propulsion for separation of the Command Module and Service Module prior to the reentry phase. The engine thrust chambers are the on-off (bang-bang) type units capable of delivering one hundred pounds of vacuum

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thrust. The complete system consists of four similar reaction control systems. These systems operate simultaneously during normal operation. Each individual propellant system consists of a pressurized helium storage, an oxidizer storage, a fuel storage and individual distribution subsystems.

The pressure subsystem is employed to provide propellant flow to the reaction control engines. The system is designed to operate automatically, with override controls provided for crew control. The reaction control display panel provides valve controls for propellant shutoff and displays for monitoring temperature, pressure, propellant quantities and malfunctions.

Reaction Control System - Command Module (RCS-C/M)

The reaction control system is composed of two independent systems utilizing six-pulse-modulated, pressure-fed bipropellant thrust generators each. The system provides three axis control of the Command Module prior to the onset of aerodynamic moments, roll control, and pitch and yaw damping during reentry. This system can also be employed for stabilization and attitude control of the Command Module and launch escape system during abort maneuvers. Normal operation is controlled by electrical impulses generated in the stabilization and control system. Operation of the two systems is simultaneous. In the event of a system failure, the remaining system provides adequate control to safely complete the reentry portion of a mission. The reaction control system panel provides the displays and controls for normal and emergency operations. A block diagram of the propellant systems is shown in Figure B-3.

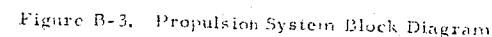
DISPLAYS AND CONTROLS

Service Module Reaction Control System

The following display and control functions will be provided on the RCS panel for the four (4) independent S/M reaction control systems:

1. Quantitative indication
 - a. Fuel tank quantity
 - b. Oxidizer tank quantity
 - c. Helium regulator outlet pressure
 - d. Package temperature

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SID 62-1438

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2. Event indication
 - a. System indication malfunction
 - b. Propellant shutoff valve operation (closed)
3. System controls
 - a. System selector switch
 - b. Propellant shutoff switches
 - c. System indicators

Command Module Reaction Control System

The following display and control functions will be provided for each of the two independent C/M reaction control systems:

1. Quantitative Indication Displays
 - a. Fuel quantity
 - b. Oxidizer quantity
 - c. Helium tank pressure
 - d. Helium regulator outlet pressure
2. Event Indication Lights
 - a. Propellant shutoff system (closed)
 - b. System indication malfunction
3. System Controls
 - a. System selector switch
 - b. Propellant shutoff switches
 - c. System indicators
 - d. System activation arm command
 - e. System activation fire command

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~~CONFIDENTIAL~~Service Propulsion System

The following display and control functions will be provided for the service propulsion system:

1. Quantitative Indication Displays
 - a. Fuel quantity (individual tanks and total)
 - b. Oxidizer quantity (individual tanks and total)
 - c. Propellant ratio indicator
 - d. Fuel tank pressure
 - e. Oxidizer pressure, engine inlet
 - f. Helium tank pressure
 - g. Helium tank temperature
2. Event indication displays
 - a. Prop. valve (4) operation (open)
 - b. Chamber wall temp high
 - c. Helium reg shutoff valves (2) operate
3. System controls
 - a. Helium reg shutoff valves (2) operate command (on-off)
 - b. Propellant ratio valve (lean-rich) command

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COMMUNICATION AND INSTRUMENTATION SYSTEM

SYSTEM DESCRIPTION

The communication equipment provides voice, television, telemetry, tracking and ranging communications between the spacecraft and the ground stations during flight operations, and provides telemetry, ranging, tracking, and voice communications with the LEM during lunar operation. Intercommunications equipment, television equipment, and digital data processing equipment are also provided. For use during rescue operations, emergency voice communications and radio recovery beacons are included.

The instrumentation equipment monitors the operation of various spacecraft equipment and provides detection and displays for operations of the spacecraft. The spacecraft central timing equipment provides data for synchronism of on board equipment and for the time displays. A tape recorder is provided to store data on board for delayed transmission and/or for recovery with the spacecraft.

Figure B-4 is a block diagram of a simulated communications and instrumentation system.

Displays and Controls

Displays and controls are provided for the following communications and instrumentation subsystems:

1. Communications and data
2. Television
3. Antennas
4. Central timing

Communications and Data Subsystem

1. DSIF operational mode selection (7 modes)
2. DSIF power mode selection (5 modes)
3. Pulse code modulation format selection (2 modes)

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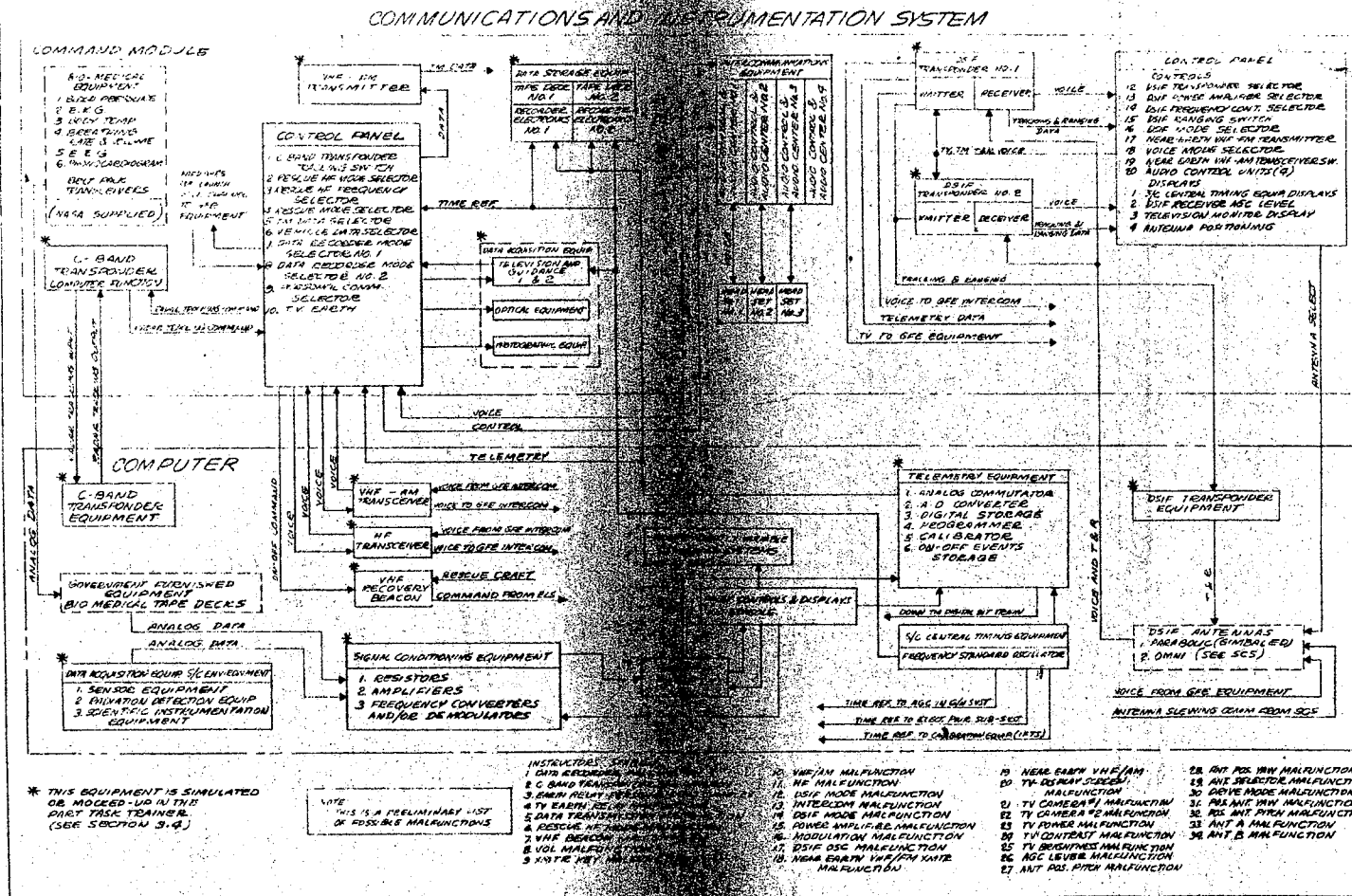


Figure B-4. Communications and Instrumentation System Block Diagram

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4. DSIF oscillator mode selection (3 modes)
5. Radio relay circuit selection (2 modes)
6. C-band transponder ON-OFF command
7. VHF FM transmitter ON-OFF command
8. VHF AM transceiver mode selection (3 modes)
9. VHF AM transceiver frequency selection (2 frequencies)
10. HF transceiver mode selection (3 modes)
11. VHF recovery beacon mode selection (3 modes)
12. Tape recorder ON-OFF command
13. Tape recorder mode selection (3 modes)
14. Tape recorder speed/direction selection (4 modes)
15. Voice operated relay sensitivity adjustment
16. Audio volume adjustment
17. VHF AM audio mode selection (3 modes)
18. HF audio mode selection (3 modes)
19. DSIF audio mode selection (3 modes)
20. Intercommunication audio mode selection (3 modes)
21. Transmitter keying mode selection (2 modes)

Television Subsystem

1. Television ON-OFF command
2. Television and readout display (not operable)

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Antenna Subsystem

1. Automatic gain control level indicator
2. High gain antenna position (pitch, yaw) indicator
3. High gain antenna deployment completion indicator
4. DSIF antenna selection (2 antennas)
5. High-gain antenna deploy command
6. High-gain antenna drive mode selection (2 modes)
7. High-gain antenna position command (pitch, yaw)

Central Timing Subsystem

Means are provided for the display of Greenwich Mean Time. The GMT display is manually correctable. A nonelectric backup GMT display is also provided. Means are provided for the display of time to and from event. The display accommodates two independent events. The display is manually presettable and capable of manual initiation.

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ENVIRONMENTAL CONTROL SYSTEM (ECS)

SYSTEM DESCRIPTION

The environmental control system provides and controls the environment in which the flight crew must operate and also provides cooling for items of electronic equipment as required.

Provisions are included for a water management program which supplies both potable water and water for sanitation needs. The systems also provides for dissipation of the major portion of the spacecraft excess internal heat load. Also considered are the storage and regulation of an independent oxygen supply to the Command Module cabin and pressure suit connections for use during the reentry phase.

Regenerative conditioning of the Command Module atmosphere includes the following:

1. The removal of debris, carbon dioxide, and trace contaminants.
2. The addition of sufficient oxygen for metabolic needs and pressure control.
3. Temperature and relative humidity control.

Operation is automatic and control is obtained through electrically actuated, manual and pressure regulator type valves. Critical system areas are provided with manual override capabilities. Figure B-5 is a block diagram of a simulated environmental control system.

Displays and Controls

Displays and controls are provided for the environmental control system as listed below.

Environmental Control System (Liquid)

Displays:

1. Evaporator outlet (steam) temperature
2. Coolant inlet temperature

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ENVIRONMENTAL CONTROL SYSTEM (ECS)

COMMAND MODULE:

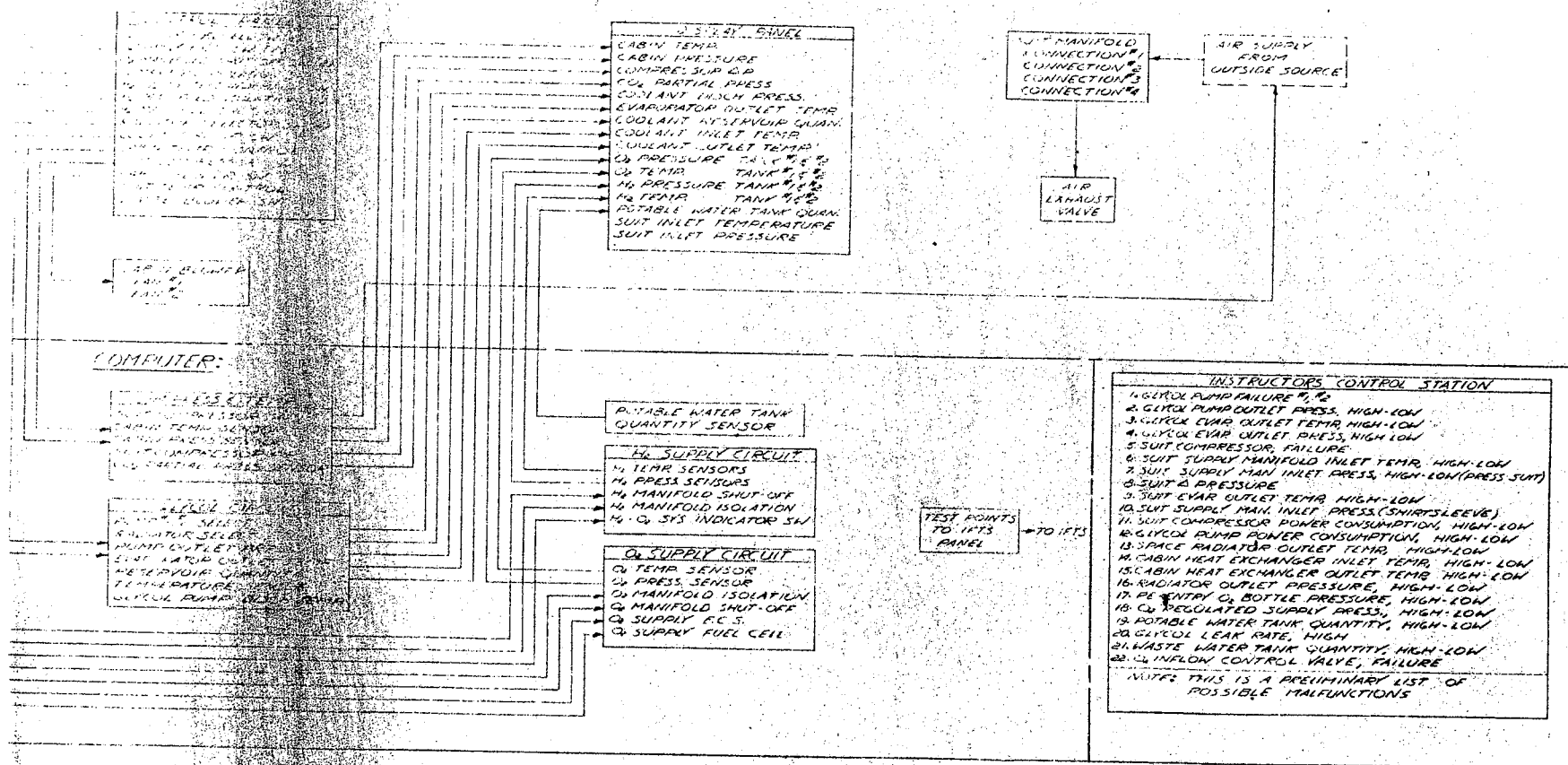


Figure B-5. Environmental Control System Block Diagram

B-31, B-32

SID 62-1438

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3. Coolant outlet temperature
4. Coolant discharge pressure
5. Coolant reservoir quantity
6. Potable water tank quantity

Controls:

1. Coolant pump selector (2 pumps)
2. Radiator selector (4) operation command

Environmental Control System (Gas)

Displays:

1. CO₂ partial pressure
2. Compressor ΔP
3. Cabin pressure
4. Suit inlet pressure
5. Cabin temperature
6. Suit inlet temperature

Cryogenic Storage System

Displays:

1. Hydrogen pressure (tank 1 and 2)
2. Oxygen pressure (tank 1 and 2)
3. Hydrogen temperature (tank 1 and 2)
4. Oxygen temperature (tank 1 and 2)

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Controls:

1. Hydrogen manifold shutoff SW. (2)
2. Hydrogen manifold isolation SW. - inlet-outlet
3. Oxygen supply ECS SW. (2)
4. Oxygen supply fuel cell SW. (2)
5. Oxygen manifold shutoff SW. (2)
6. Oxygen manifold isolation SW.
7. $O_2 H_2$ system indication SW.

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ELECTRICAL POWER SYSTEM (EPS)

SYSTEM DESCRIPTION

The electrical power system controls and regulates power, converts power, stores electrical energy, distributes power, and tests the over-all electrical system. The system utilizes redundant subsystems to convert, regulate, and distribute required DC and AC power to the individual spacecraft systems at the required time. The system functions are regulated automatically. Manual selection and control of individual functions and system test override controls are also provided.

The Service Module electrical power system generates and distributes electrical power and also stores, distributes, regulates and controls the reactants provided for the electrical power supply and environmental control system.

Figure B-6 is a block diagram of a simulated electrical power system.

Displays and Controls

The following displays and controls are provided for the electrical power system.

Power Distribution Display Panel No. 1 - Controls

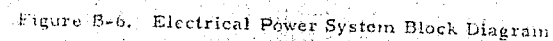
Bus A - Fuel Cell 1, 2, and 3. Three 2-position maintaining ON-OFF switches which turn power on or off from fuel cells 1, 2, and/or 3 to bus A.

Bus B - Fuel Cell 1, 2, and 3. Three 2-position maintaining ON-OFF switches which turn power on or off from fuel cells 1, 2, and/or 3 to bus B.

Ground Power - Bus A and Bus B. Two 2-position maintaining ON-OFF switches which turn power on or off from the ground bus to spacecraft bus A and/or bus B.

Post Ldg. Bus - Battery A, B, and C. Three 2-position maintaining ON-OFF switches which turn power on or off from post landing batteries A, B, and/or C to the post landing bus.

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Power Distribution Display Panel No. 2 - Controls

Indicator Select. The selectors are pushbutton interlocking type and select which of the ten items will be displayed on the DC volts and DC amps meters.

The items are:

1. F/C 1, 2, and 3
2. Battery A, B, and C
3. Bat charge
4. Bus A and B
5. PL bus

Under Voltage Reset. Momentary pushbutton switch which permits the entry batteries to be disconnected from the main DC buses (RESET position).

Battery A, B, and C. Three 3-position maintaining ON-OFF switches which permit the undervoltage sensing circuit to operate normally (NORM position), keep the entry battery off the DC buses if an undervoltage condition exists (OFF position), or connect the battery to the DC buses if no undervoltage condition exists (ON position).

Power Distribution Display Panel No. 2 - Displays

DC Volts and DC Amps. Two meters which display the voltage and current from FC 1, FC 2, FC 3, battery A, battery B, battery C, battery charger, or the voltage only on bus A, bus B, or post landing bus, as selected by indicator select pushbutton.

Output DC Bus Undervoltage. Indicator lamp; indicates the condition of a relay (closed in the relaxed state) connected to the main DC relay bus. Lamp signals when the voltage on the main DC relay bus falls below a limit value.

Power Distribution Display Panel No. 3 - Controls

Component Temperature Selector. The selectors are pushbutton interlocking type and select which of the seven items will be displayed on the component temperature meter.

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The items indicated are:

1. Inv 1, 2, and 3
2. Bat A, B, and C
3. Sequencer

Battery Charge Selector. Four pushbutton interlocking type selectors. The battery charger is connected to battery A, B, or C, or OFF as selected.

Bus Ind Control. One 2-position, 1-2, selector switch. Selects the bus parameters to be displayed on the AC volts and frequency meters.

Indication Selector. The selectors, A, B, and C, are pushbutton interlocking type. These selectors work in conjunction with the selected Bus Indicator and display the selected parameters on the AC volts and frequency meter.

Inverter DC Input. Three 2-position maintaining ON-OFF switches which turn on or off the DC power to the respective inverters.

Inverter AC Bus 1 and Bus 2. Six 2-position maintaining ON-OFF switches which connect respective inverters (1, 2, or 3) output to AC bus 1 or AC bus 2. The controls are interlocking so that at any one time only one Inverter can be connected to one bus.

Power Distribution Display Panel No. 3 - Displays

Comp Temp Meter. One meter which displays the temperature of the component selected by the component temperature selector.

AC Volts Meter. One meter which displays the voltage of any one of the 3 AC phases on either of the 2 busses as selected by the indication selector and the bus indicator control.

Frequency Meter. One meter which displays the actual frequency on bus selected by the bus ind control.

AC No. 1 and No. 2 Fail. Two indicator lamps indicate information from frequency sensors on bus 1 or bus 2. Lamps signal when the frequency exceeds a limit value.

Inverter Overheat. Indicator lamp indicates information from temperature sensors on the inverters. Lamp signals when an inverter's temperature rises above a limit value.

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Fuel Cells Display Panel - Controls

System Indication Selector. The selectors, OFF, 1, 2, and 3, are pushbutton interlocking type. They select which of the 3 fuel cells parameters will be displayed on the meters and which fuel cell will be affected by the activation of H₂ purge or O₂ purge controls. Indicator lamps located behind switches 1, 2, 3, illuminate when limits are exceeded in that fuel cell system regardless of switch position.

Purge H₂ and O₂. Two 2-position maintaining start-stop switches. Switch energizes vent valve which allows purge gas to flow (START position). Lamps behind the start section of the switch signal when the respective FC purge valve is open.

Pump 1, 2 and 3. Three 2-position maintaining ON-OFF switches which turn on or off the respective pumps.

Squib Arm 1, 2 and 3. The selectors 1, 2 and 3 are pushbutton type and arm the respective F/C's gas supply reactants isolation valve squib.

Reactants Isolation. Pushbutton control, ISOLATE, when depressed causes selected armed isolation valve to be blown shut.

Reg Out Pressure Selector. The selectors O₂, H₂, and N₂ are pushbutton interlocking type. They control which reg out pressure is displayed but do not control the indicator lamps located behind the switch. The lamps signal when a respective gas reg out press. goes outside a limit value, regardless of switch position.

Mod Temp Selector. The selectors, cool, skin, exh, are pushbutton interlocking type. They control which temp is displayed. Indicator lamps located behind switches illuminate when temp exceeds limits regardless of switch position.

PH Selector. The selectors, IND. and COLL, are 2-position maintaining switches. IND. selection displays PH value for the respective selected system. COLL, selection displays PH value in H₂O line between F/C and C/M. Indicator lamp located behind "IND." illuminates if PH exceeds limits in individual fuel cell.

Flow Rate Selector. The selector, H₂ and O₂, is on a 2-position maintaining switch which selects the flow rate to be displayed on the meter. Indicator lamps located behind H₂ and O₂ switches illuminate when limits are exceeded regardless of switch position.

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Power Distribution Display Panel No. 3 - Displays

Reg Out Press Meter. Meter displays information from the pressure sensors at the outlet of the regulators in the H₂, O₂, and N₂ lines as selected by the selector switch.

Mod Temp Meter. Displays information from temperature sensors located on the FC skin, in the glycol line at the FC module inlet and in the FC condenser exhaust line as selected by the selector switch.

P^H Meter. Meter displays information from P^H sensor selected by the selector switch.

Flow Rate Meter. Meter displays information from flow rate sensors located in the H₂ and O₂ supply lines as selected by the H₂ - O₂ selector.

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LAUNCH ESCAPE SYSTEM (LES)

SYSTEM DESCRIPTION

The function of the launch escape system is to separate the Command Module from the Service Module and to deflect it from the trajectory of the boosters in the event an abort of the mission is required. If an abort signal is received before lift-off the launch escape system must have sufficient thrust to lift the Command Module to a minimum altitude of 4000 feet and to translate it laterally at least 3000 feet at apogee to allow safe deployment of the earth landing system. A block diagram of a simulated launch escape system is shown in Figure B-7.

The launch escape system is comprised of a main launch escape motor of approximately 155,000 pounds thrust at sea level and 70 F for vertical lift of the Command Module, a kicker motor of approximately 3100 pounds thrust for lateral translation of the system, and a tower jettison motor of approximately 33,000 pounds thrust for pulling the launch escape tower and motors out of the trajectory of the spacecraft approximately 15 seconds after ignition of the second stage booster following normal launch or immediately prior to deployment of the earth landing system in the event of an abort. The operation of the system is controlled by the integrated abort system of the launch vehicle with pilot command override.

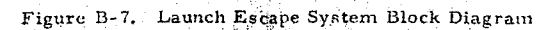
Displays and Controls

The displays and controls of the launch escape system are composed of the following:

Displays:

1. Abort sequence ready
2. Abort sequence initiate operation
3. LES tower mechanism release completion
4. LES tower mechanism not released

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Controls:

1. Abort sequence arm command
2. Abort sequence initiate command
3. Tower jettison sequence initiate command
4. Launch escape motor fire command

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EARTH LANDING SYSTEM (ELS)

SYSTEM DESCRIPTION

The earth landing system provides Command Module stabilization and reduces vertical landing velocity from any mission or abort operation. The system stabilizes the Command Module following reentry into the earth's atmosphere.

Stabilization is accomplished by a drogue parachute during early descent and by a group of three landing parachutes during the remainder of the descent. The system includes manual controls for disconnecting the main parachutes, ejecting the SOFAR bomb and dye marker, and erecting the post landing HF and VHF antenna. Figure B-8 is a block diagram of a simulated earth landing system.

The earth landing system is normally deployed by pilot command following reentry and at a maximum altitude of 25,000 feet. In the event of an abort of the mission in which the launch escape system is operated the earth landing system sequence will be initiated automatically three seconds after ignition of the escape tower jettison motor.

Any of the recovery operations can be started at any time by pilot command except the erection of the VHF antenna which is delayed for 15 seconds following the pilot command; and the release of the main parachute bridles, and the deployment of aids to navigation which are delayed for twenty seconds following the pilot command.

Displays and Controls

The displays and controls for the earth landing system are as listed below:

Displays - event indicator:

1. Earth landing sequence ready
2. Forward heat shield jettison completion

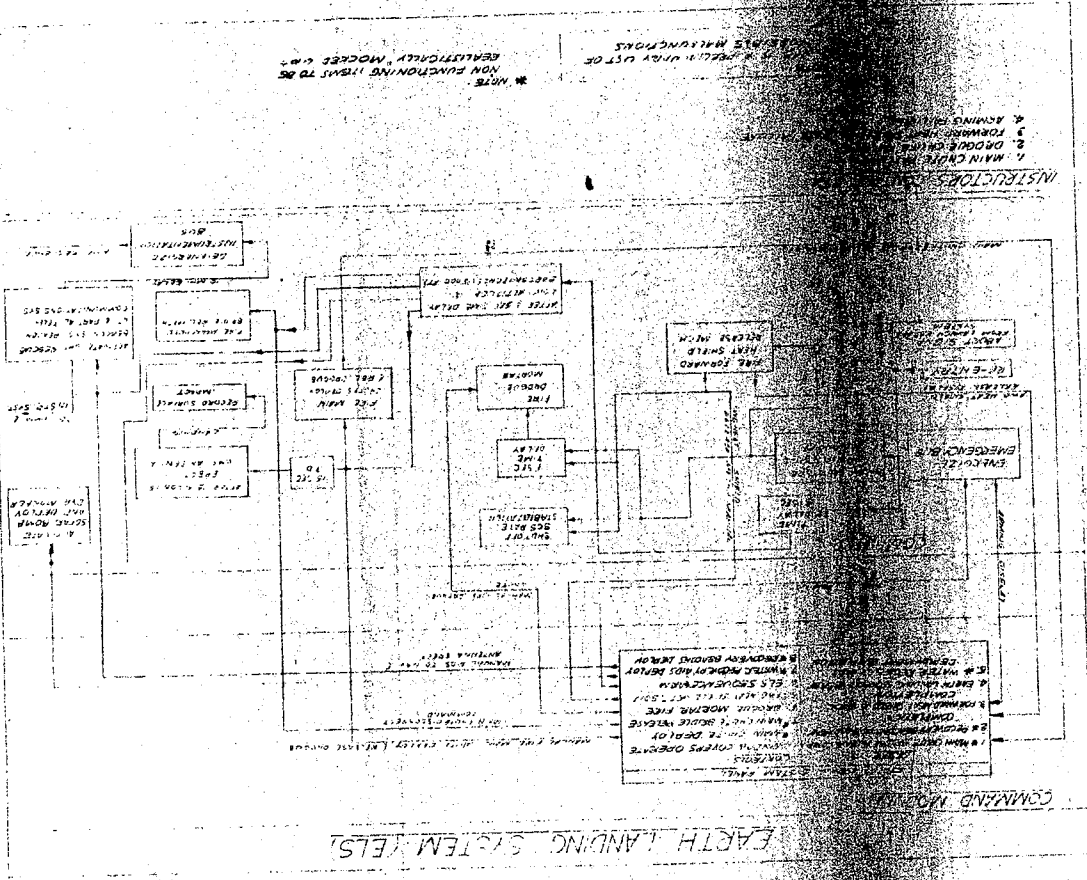
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EARTH LANDING SYSTEM YELLS

COMMAND MODULE



INSTRUCTIONS
1. MAIN ENGINE
2. DROGUE CHUTE
3. FORWARD CHUTE
4. ACHING
5. MAIN CHUTE
6. DROGUE CHUTE
7. FORWARD CHUTE
8. ACHING
9. MAIN CHUTE
10. DROGUE CHUTE
11. FORWARD CHUTE
12. ACHING

Figure B-8. Earth Landing System Block Diagram

D-51, D-52

SID 62-1438

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3. Main chute bridle release completion*
4. Water recovery aids deployment completion*
5. Recovery beacons deployment completion*
6. Drogue chute deployment completion

Controls:

1. ELS sequence arm command
2. Window covers operate command
3. Forward heat shield jettison command
4. Drogue mortar fire command
5. Main chute deploy command*
6. Main chute release command*
7. Water recovery aids deploy command*
8. Recovery beacons deploy command*

Other:

A barometric pressure display is provided for event monitoring of baroswitch operation during the recovery phase and for quantitative pressure altitude indication under low altitude, low mach number conditions.

*Indicates an item of equipment which will be nonfunctioning on the trainer.

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IN-FLIGHT TEST SYSTEM (IFTS)

SYSTEM DESCRIPTION

The In-flight test system provides the crew with a rapid check on the status of the spacecraft systems and also indicates the faulty module.

The In-flight test system provides a GO-NO GO test point readout showing which spacecraft system and subsystem failed, a means for manual testing, maintenance instructions, and a centralized panel to provide for ground checkout and telemeter data requirements.

Figure B-9 is a block diagram of the In-flight test system. The principal subsystems are as follows:

1. Central panel
2. Programmer
3. Switching complex
4. Comparator
5. Crew readout
6. Stimuli generator
7. Manual test unit

Central Panel

This panel is the termination area for all test point wiring originating in the spacecraft systems to be monitored by the IFTS or used in manual testing.

Programmer

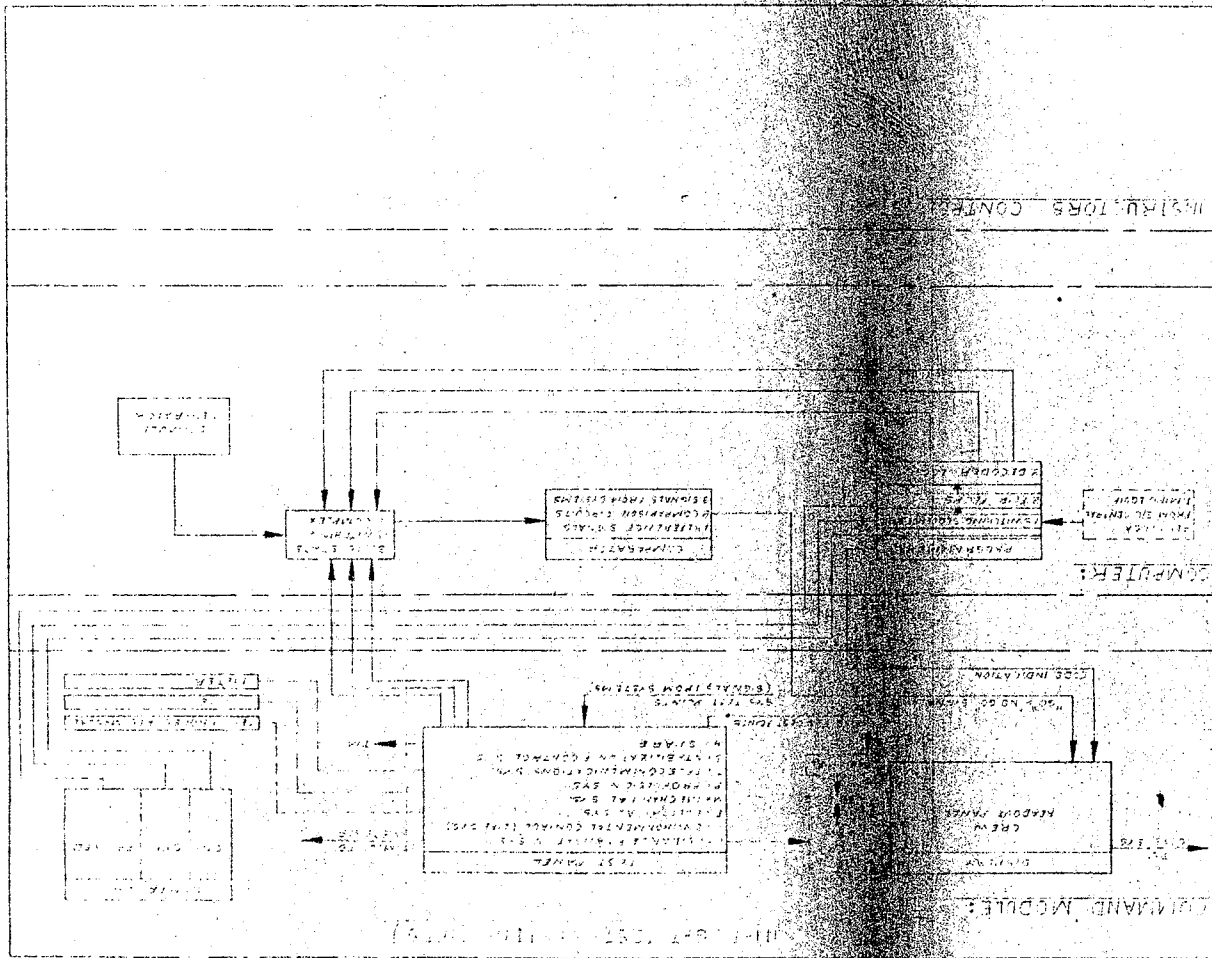
A sequence which controls the switching complex and comparator.

Switching Complex

Connects the test points to the comparator.

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Figure B-9. In-Flight Test System Block Diagram



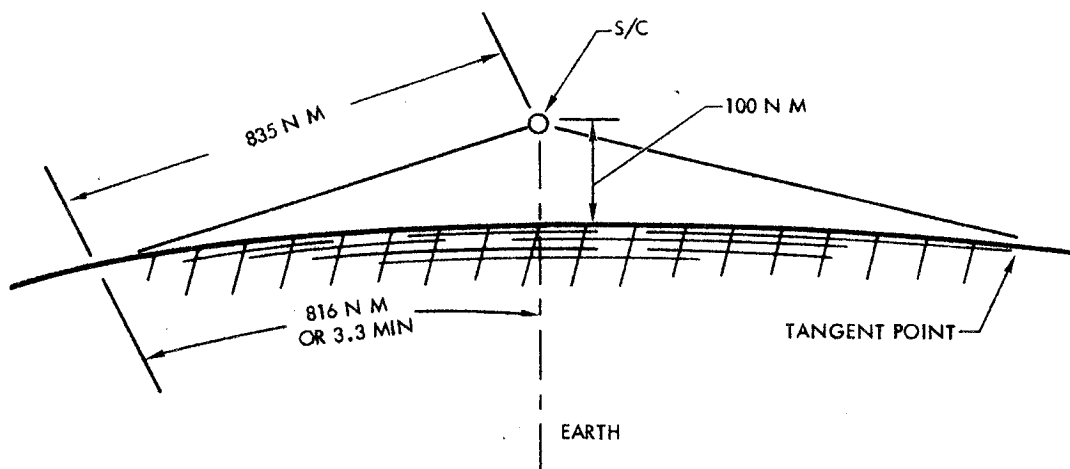
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Figure B-10. Geometry of Earth Orbit

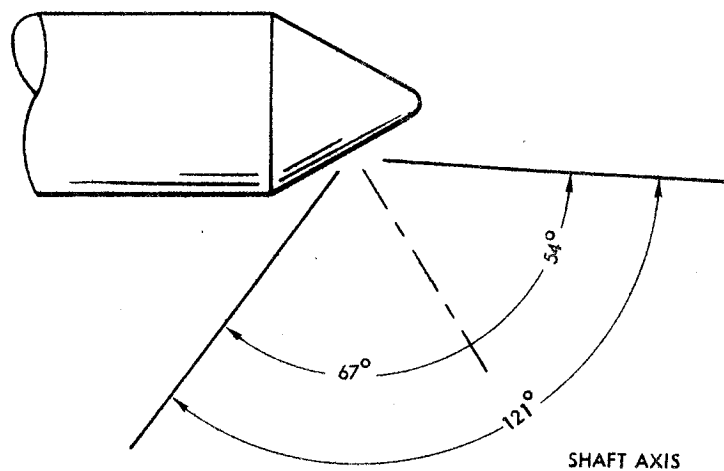


Figure B-11. Total Coverage of SCT at 25° Offset Search Mode Position

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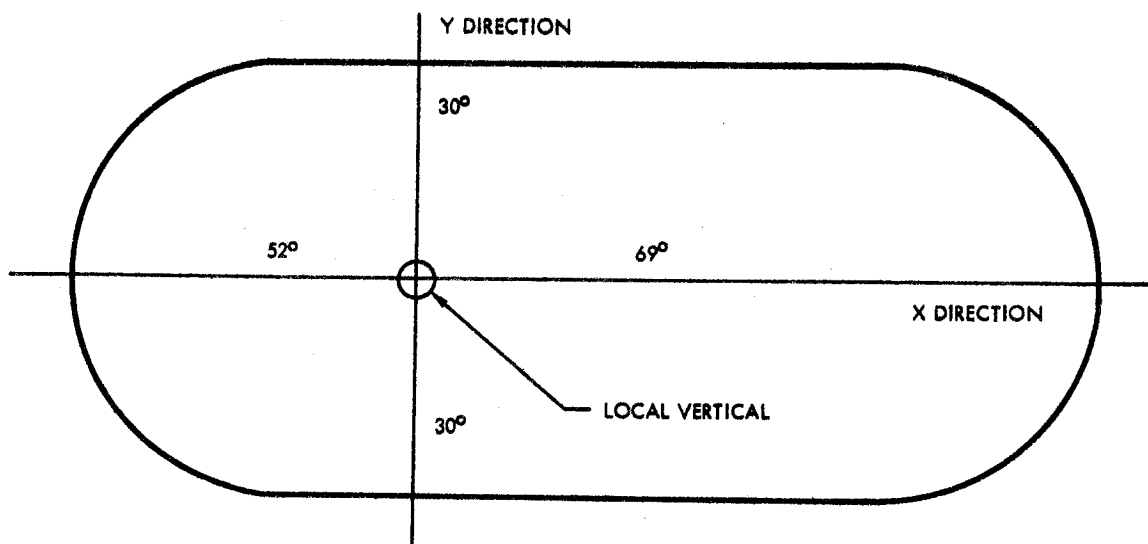
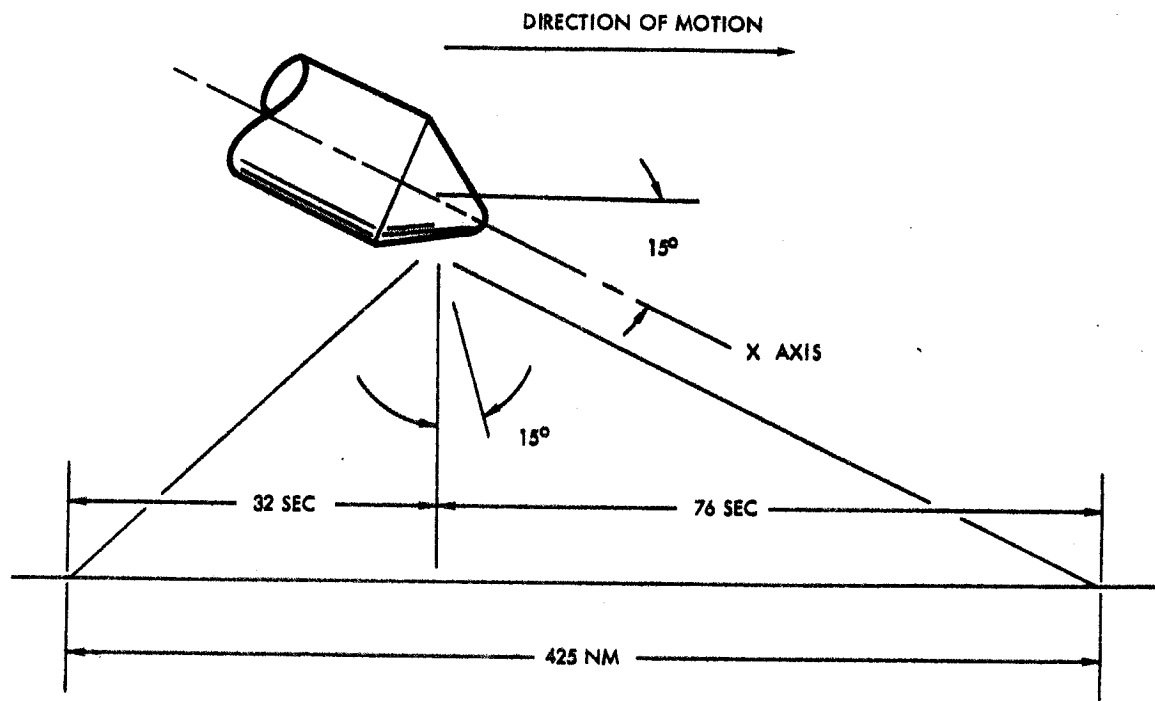
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Figure B-12. View on Surface for Trunnion Axis Freedom

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center, and mark the landmark. Other functions must be performed, however, before the landmark is acquired.

Procedure

The orbit determination sighting procedure may be broken down into the following steps.

Preparation. During the preparation phase many things must be done. The first function will be to properly position the vehicle in attitude, if it is not already so. The required attitude is shown in Figure B-12. While the attitude is being changed, the operator will determine which landmark will be coming up next. He will then select the chart in the viewer which shows the landmark and surrounding area. The telescope shaft axis will be locked at zero, and the trunnion axis rotated up about 25 degrees. At this time the operator will look through the telescope to acquire the landmark. If the orbital parameters are well enough known so that the out-of-plane error may be determined, a roll maneuver is initiated prior to acquisition. This will do two things: (1) help in acquisition, and (2) decrease the time required to center the landmark.

Acquisition. Once the initial preparations have been completed the operator will begin looking through the telescope. The 60 degree field of view will be used to give maximum visibility of the earth surface. Having looked at the slide stored in the viewer of the area near the landmark, the operator will be able to recognize when he is in the vicinity of it. A landmark may be almost anything which is recognizable and has a distinguishing mark on it. The size of the landmark may be about 1 to 10 miles with a distinguishing mark of about 0.5 miles. Typical landmarks could be coastlines, islands, lakes, or cities. Once the basic landmark has been acquired, the centering phase will start.

Centering and Marking. The centering phase is the most critical phase in an orbit determination sighting. Once a landmark has been acquired there will be only a short time for the centering. This time will be about 60 seconds. As was mentioned earlier, it is desirable to make more than one reading from the same landmark.

The first maneuver to perform in centering the landmark is to roll the vehicle until the landmark is positioned on the "R" line. The operator will use the attitude hand controller to perform the roll maneuver. Once the landmark is on the "R" line, minimum impulse control will be used to maintain that alignment. Next the trunnion angle will be slewed out until the crosshairs are about centered on the landmark. The magnification of the SCT will then be switched to 3X and fine adjustments will be made to place the crosshairs over the distinguishing feature of the landmark. When the feature is well centered, the CDU lock button is pressed.

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Midcourse Navigation Sighting

The following is a detailed procedure of how a midcourse navigation sighting is performed. The angular coverage provided by the optics is assumed to be as shown in Figure B-13. The SCT field of view is shown as it will be for the SCT slaved to the 25 degree offset position and with the trunnion axis parallel to the command module pitch axis.

During the navigation sighting, the command module will be orientated such that the shaft drive axis will be along the landmark line of sight. For minimum reorientation time and fuel requirements between sightings it is also desirable to have the plus roll axis orientated toward the earth-moon line of centers. Orientation maneuvers when changing between earth and moon landmark sightings will then be performed predominantly in roll with small pitch angle changes. The trunnion axis of the SXT will be aligned perpendicular to the plane defined by the landmark and star line of sight.

The midcourse navigation sighting procedure is composed of two parts. The first part describes the tasks necessary to prepare the lower equipment bay for navigation sightings and the second part describes the tasks necessary for each measurement. It is assumed that the SCS attitude reference is operating and aligned. It is also assumed that the G&N optics have been zeroed.

1. Preparation
 - a. Press computer power switch to "ON."
 - b. Switch optics power switch to "ON."
 - c. Switch "Map and Data Viewer" power switch to "ON."
 - d. Select "procedure" film strip with "film selector."
 - e. Crank viewer to procedure for "Midcourse navigation fix - IMU on standby," and identify time at which procedure is to begin.
 - f. Press "VERB" button on keyboard.
 - g. Select G&N mode "VERB" code (for "navigation") from viewer.
 - h. Insert "VERB" code in keyboard.
 - i. Press "Enter" button on AGC keyboard.
 - j. Observe correct "VERB" code on display.
 - k. Press "NOUN" button on keyboard.
 - l. Select G&N mode "NOUN" code (for "midcourse - IMU on standby") from viewer.
 - m. Insert "NOUN" code in keyboard.
 - n. Press "Enter" button on AGC keyboard.

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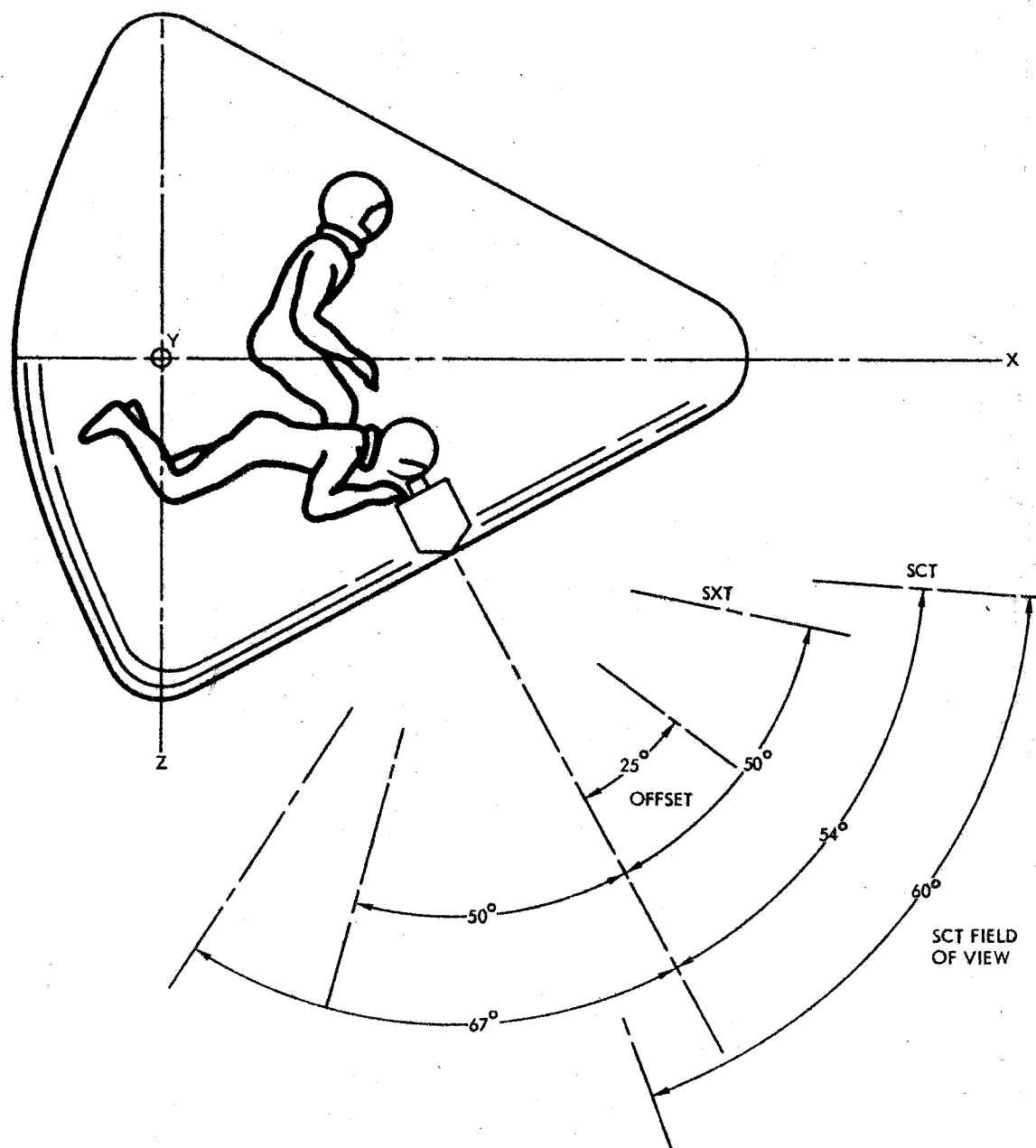
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Figure B-13. Optics Coverage

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- o. Observe correct "NOUN" code on display.
- p. Request SCS mode for "SCS attitude control" at main display panel.

2. Measurements

- a. Select "Landmark LOS 0°" on telescope slave control.
- b. Select "Resolved" on optics controller mode switch, and select "normal" on optics zero selector.
- c. Select "Hi" on optics speed control switch.
- d. Determine "star" and "star map" (required for orientating positive roll axis) from viewer.
- e. Select "map" film strip with "film selector."
- f. Crank viewer to star map required.
- g. Identify star on star map.
- h. Identify star through window.
- i. Orientate command module so that positive roll axis is directed approximately toward the reference star.
- j. Select "procedure" film strip on viewer.
- k. Determine "landmark" and "landmark map" from procedure.
- l. Select "map" film strip on viewer.
- m. Crank viewer to landmark map required.
- n. Identify landmark on map.
- o. Select "times one" power for SCT eyepiece, and drive trunnion angle to zero.
- p. Acquire earth or moon in SCT field of view.
- q. Identify landmark in field of view of SCT.
- r. Center landmark in field-of-view using three axis hand controller (see Figure B-14).
- s. Identify landmark in SXT field-of-view.

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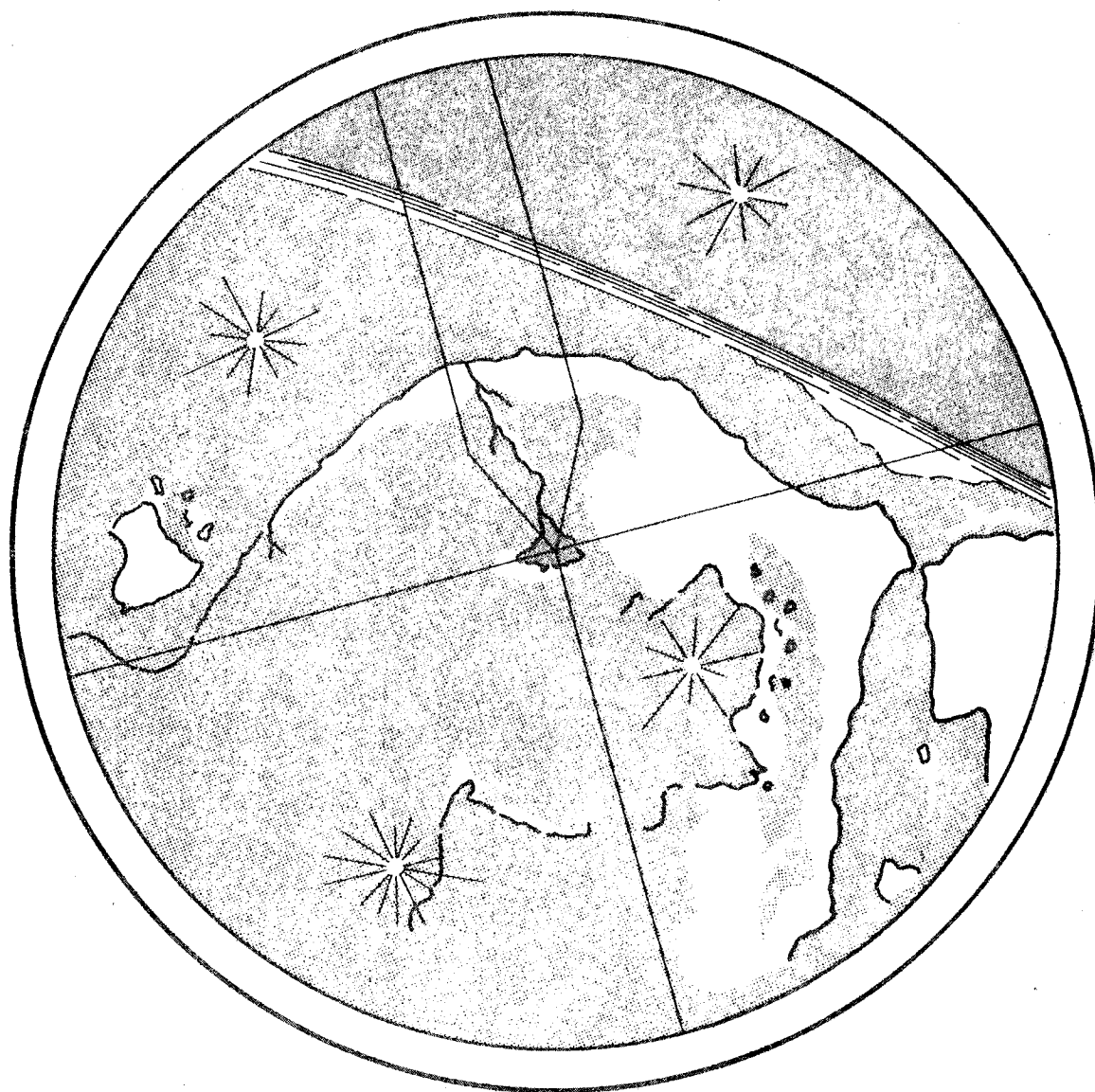


Figure B-14. Landmark and Star Juxtaposition

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- t. Center landmark image in SXT field-of-view with minimum impulse control.
- u. Request 0.5 degree SCS deadband.
- v. Select "offset 25 degrees" on telescope slave control.
- w. Select "procedure" film strip on viewer.
- x. Determine "navigation star" and "star map" from procedure.
- y. Select "map" film strip on viewer.
- z. Crank viewer to star map required.
- aa. Identify star on star map.
- bb. Acquire star in SCT field-of-view with shaft axis rotation.
- cc. Align star with principal axis of SCT so that star is in center half of field-of-view.
- dd. Select "times one" power on SCT eyepiece.
- ee. Select "MEDIUM" on optics speed control switch and "Star LOS" on "Slave telescope" control.
- ff. Identify star in SCT field-of-view.
- gg. Realign star with principal axis of SCT within center half of field-of-view.
- hh. Select "times three" power on SCT eyepiece.
- ii. Identify star in SCT field-of-view.
- jj. Realign star with principal axis of SCT within center sixth of field-of-view.
- kk. Select "direct" on optics controller mode switch.
- ll. Select "low" on optics speed control switch.
- mm. Identify star in SXT field-of-view.

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- nn. Bring star image to within 0.5 degrees of principal axis of SXT field-of-view with optics controller.
- oo. Drive star image toward launch mark image with trunnion motion using optics controller.
- pp. Select five degree deadband.
- qq. Align star with imaginary line through center of landmark image until parallel to M lines.
- rr. Press "MARK" button when images are aligned as described in step qq.

IMU Alignment

The function of the IMU in the Guidance and Navigation System is to provide a known inertial reference. A known inertial reference is required during powered velocity changes (ΔV), orbital navigation sightings, and entry. For powered velocity changes, vehicle attitude is supplied by the IMU and the IMU accelerometers monitor the velocity change. For orbital navigation the SCT provides angular information with respect to the navigation base, and the IMU provides the navigation base to inertial angular information. During entry the IMU accelerometers sense velocity changes due to atmospheric drag and is used to control the vehicle in roll.

Procedure

Star Sighting. To have the platform aligned to a known inertial attitude, sightings are made to two different stars using the sextant. The only constraints on the vehicle attitude due to the use of the sextant is that the sextant shaft axis is pointing out into space. One LOS of the sextant will contain stars.

The first step in the alignment procedure is to acquire a known star. This is accomplished by sighting through the telescope, recognizing the star pattern, and selecting a cataloged star in the field-of-view as shown in the S/C viewer. The selected star is then centered in the telescope by using the shaft and trunnion controls. Next the operator sights through the sextant and observes the selected star and centers it. When the star is centered the operator presses the mark button. The computer then records the SXT trunnion and shaft angles and IMU gimbal angles to insure that these angles are associated with a particular star, the operator enters into the computer keyboard the star identification.

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To make the second sighting the telescope is moved so that its field-of-view encompasses a different star field and the above procedure is then repeated.

During the time the sightings are made the CDU is in a follow mode. In this mode, as the platform is torqued or it drifts, the resolvers on the gimbals send the new angular positions to the CDU resolvers. The CDU resolvers compare their position and the IMU resolver position to generate a difference signal. This difference signal goes to the CDU shaft drive motors, which rotate the resolvers until the difference signal goes to zero. The resolvers in the IMU and CDU are now at the same angular position. The encoder on the CDU shaft transmits the angular position to the AGC.

Alignment. The actual IMU alignment procedure may be divided into two phases; coarse and fine align. In the coarse alignment mode the gimbals are torqued directly at a high rate and the gyros are in a "caged" mode. In the fine align mode the gyros are torqued by the computer at a slow rate which in turn torque the gimbals to the desired orientation.

Coarse Alignment. Figure B-15 shows the signal flow for a coarse IMU alignment. The required two angles to be stored in the AGC may come from the following sources: Two star line-of-sight readings taken using the sextant. The procedure for using the sextant is as described above.

The computer, using the stored angles, determines the desired orientation of the IMU with respect to the vehicle frame. This angular command is then sent to the CDU to position the resolver shafts. An encoder on the CDU shaft transmits the actual shaft position back to the computer closing the loop. A difference now exists between the resolver positions in the IMU and CDU. Due to this position difference, an error signal is generated in the CDU. This error signal is amplified in the PSA and sent to the IMU where the gimbals are driven. The output of the gimbal resolvers in the IMU is sent to the CDU. When the difference between the resolvers goes to zero, the error signals becomes zero and the IMU is coarse aligned. During the coarse alignment torquing phase, the gyros in the IMU are electrically "caged." At the end of the alignment the gyros will still be at zero, at which time they are uncaged.

Fine Alignment. After the IMU has been coarse aligned, the operator will initiate the fine align mode. He will make the sighting on two stars as described previously and the computer will start the fine alignment. In this mode the AGC monitors the vehicles attitude drift via the CDU during the fine alignment procedure prior to gyro torquing and this drift is accounted

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for in the alignment. There still will be a slight error due to gyro drift and the linearity of the gyro scale factors during gyro torquing. The accuracy of the fine align is about 1 arc minute.

Figure B-16 shows the block diagram for fine alignment. The computer again determines the desired attitude of the platform, but this time the command is sent to the IMU gyros in the IMU. When the gyros are torqued they develop an error signal which is sent to the PSA and amplified. The amplified signal is then sent back to torque the gimbals of the IMU. This completes the fine alignment procedure for the IMU.

The operator may now initiate any maneuver which requires prior IMU alignment. The time required to perform the fine alignment is about five minutes. This time includes the sighting of two stars and the gyro torquing of the platform.

IMU Alignment During Orbit

The SCT shaft axis will be pointed away from earth toward a star within $\pm 50^\circ$. A roll rate of 0.7 min/sec may be tolerated. This procedure may have two courses; one, the angular sighting may be between a known star and a Lunar landmark or; two, between two sets of stars in different planes.

There will be two alignments per orbit with the first being performed immediately after injection and the second approximately 1/2 orbit later.

IMU Alignment During Mid-Course

The IMU alignment during mid-course will be similar to that of IMU alignment during orbit with the exception that during the early portion of mid-course maneuver sightings will be on an earth landmark and a fixed star while the latter portions of the mid-course maneuver will sight on a lunar landmark and a fixed star.

It is expected to have three alignments spaced at 5, 20, and 50 hours after translunar injection.

Navigation Fixes of all Phases

The navigation fixes will depend mainly on the phase of the vehicle. The earth orbital phase has been considered previously whereas the other phases are considered as follows:

Translunar Mid-Course

First 3/4 of an hour after injection used for necessary maneuvering for LEM transposition.

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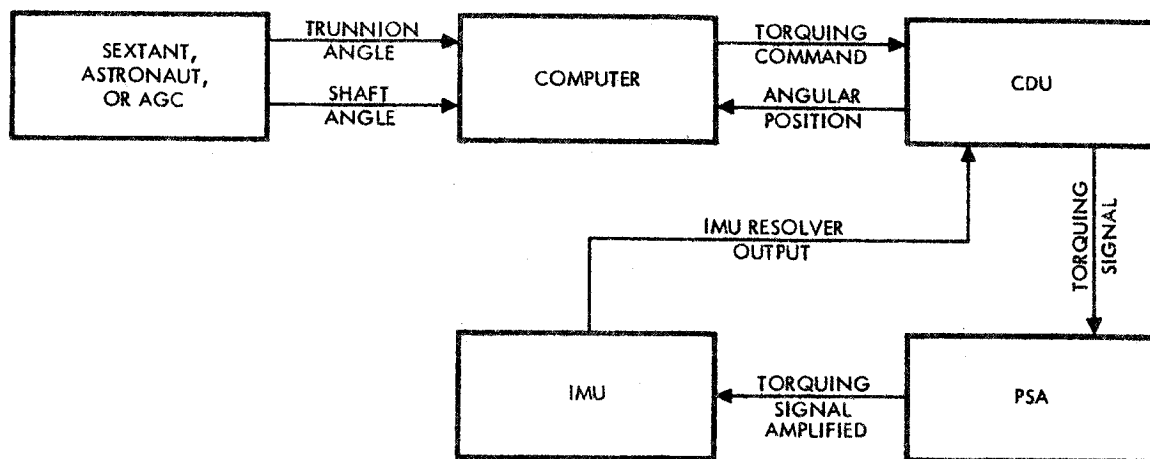
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Figure B-15. Coarse Alignment

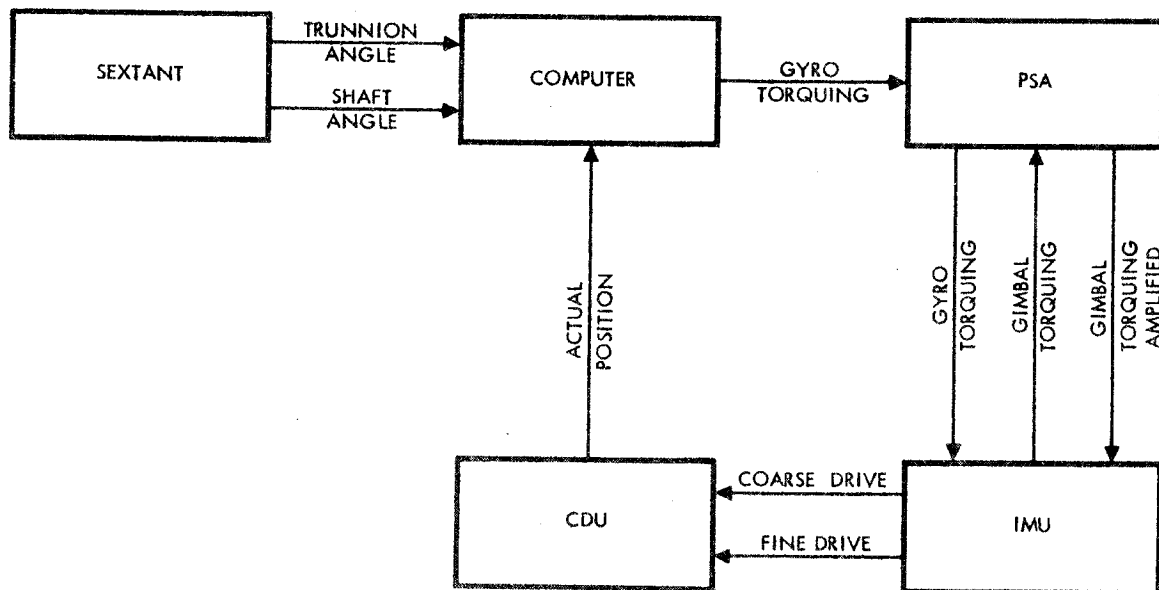


Figure B-16. Fine Alignment

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Next 4-1/4 hours vehicle orientated so that SXT shaft axis is pointed toward earth landmark. Many SXT sightings taken on a star and earth landmark throughout this period.

Next 5 hours vehicle orientation remains the same. SXT sightings taken every 1/2 hour on a star and earth landmark.

Ten hours after injection vehicle orientated with SXT shaft axis toward lunar landmark. Navigation sighting taken every 3 hours using star and lunar landmark.

Lunar Approach

A great number of fixes will be taken with the shaft axis of SXT toward lunar landmark.

Lunar Orbit

The SCT must point at the lunar landmark with the shaft axis set and locked at zero while the vehicle X, Z plane must pass through lunar landmark. The navigation fixes will be taken on illuminated portion of lunar surface in the prescribed manner: 3 lunar landmarks on first orbit; 3 lunar landmarks during orbit prior to LEM pickup; 3 lunar landmarks during orbit prior to transearth injection.

Transearth Mid-Course

First 2 hours vehicle orientated such that the SXT shaft axis toward lunar landmark. Many sightings on star and lunar landmark throughout this period.

Next 24 hours vehicle orientated with SXT shaft axis toward lunar landmark.

Next 32 hours SXT sightings taken every 3 hours on a star and earth landmark.

Beyond 58 hours continuous sightings on a star and earth landmark until preparation for entry phase is executed.

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APPENDIX C

FUNCTIONAL SYSTEMS INTEGRATION

NOMENCLATURE

C, C/M	Crew station (simulated command module)
I, I/C	Instructors' station
D,	Digital computer
A, A/C	Analog computer
ACD	Antenna control display
AUD C	Audio control
BI	Barometric indicator
BSI	Booster situation indicator
Cry D	Cryogenic display
CK and RD	Computer keyboard and readout display
CTI	Clock timer indicators
EMI	Entry monitoring indicators
ELC	Earth landing controls
FCD	Fuel cells display
FDAI	Flight director attitude indicator
GPI	Gimbal position indicator
INT D	Integrated display

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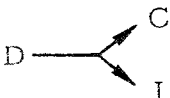
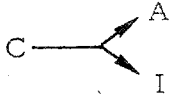

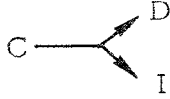
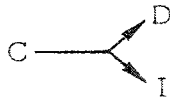
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IFTSSS	Inflight test system scan select
LEC	Launch escape control
PDD 1	Power distribution display No. 1
PDD 2	Power distribution display No. 2
PDD 3	Power distribution display No. 3
RCD	Reaction control display
SC	Separation control
SCS C	SCS control
SCS PC	SCS power control
SPD	Service propulsion display
S/M QTI	Service module quadrant temperature indicator
TC	Telecommunication panel
Δ VD	Delta V display

Note: Visual system not included in this table.

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Table C-1. Functional Systems Integration

Function	Panel	Description	Panel Status Remarks	Input - Output
A_s	ACD	Antenna select (omni-dish)	Crew control signal to digital computer, indication to instructors' station	
A_{agc}	ACD	Antenna AGC	Digital computer drive to C/M and instructors' station panel meters, noise level control of communications channel	
ACS_{gn}	SCS C	Attitude control guidance and navigation mode select	Active switch—control to A/C, indication to I/C	
ACS_{scs}	SCS C	Attitude control SCS mode select	Active switch—control to A/C, indication to I/C	
AD_c	ACD	Antenna dish control (automatic-manual, deploy-retract)	Crew control signal to digital computer, indication to instructors' station	
AP_c	ACD	Antenna position control (up-down, left-right)	Crew control commands to D/C, indication to I/C	

C-3

SID 62-1438

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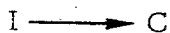
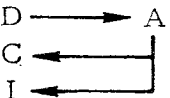

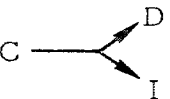
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Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
AP _i	ACD	Antenna position indication	Analog drive signal to C/M and I/C, position indication to digital computer	
A _{ec}		Attitude axes' emergency control	Crew activation causes manual commands to be routed directly to reaction jets, indication of emergency mode to I/C	
AC		Aural cues	Controlled by crew actions and/or instructor inputs from the I/C	
B _d	BI	Barometer reading	Computation in digital, to analog for drive, indication to C/M and I/C	
C _p	CRY D	Press re reading for tanks 1 and 2	Meter readings supplied from I/C, instructor adjustable	
C _{ps}	CK and RD	Computer program select	Crew control to digital computer, indication to the I/C	

C-4

STD 62-1438

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Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
C _{dc}	CK and RD	Computer controls, crew member discreet commands or control (on-off, error reset, clear, verb, noun, enter, ±range, ±track)	Crew control to digital computer, indication to I/C	
C _{ki}	CK and RD	Computer input, keyboard	Crew control to digital computer, indication to I/C	
C _t	CRY D	Temperature reading for tanks 1 and 2	Meter readings supplied from I/C, instructor adjustable	
CC	CK and RD	Computer condition signals (error, power fail, AGC fail, Enc zero)	Control from digital computer to C/M and I/C	
CD _{cr}	CK and RD	Computer display, computer readout to crew	Readout from digital computer to C/M and repeater at I/C	
CD _{θ φ, ψ}	SCS C	Roll, pitch and yaw channel disable	Active switch - control to A/C, indication to I/C	

C-5

SID 62-1438

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Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
CH _{2so}	CRY D	H ₂ shut-off control for H ₂ flow to fuel cells (tanks 1, 2)	Operable switches with indication to I/C	C → I
CH _{2i}	CRY D	H ₂ isolate control for connecting tank manifolds (in and out)	Operable switches with indication to I/C	C → I
CO _{2ecs}	CRY D	O ₂ supply control for isolating either ECS supply line from the manifold (line 1 or line 2)	Operable switches with indication to I/C	C → I
CO _{2fc}	CRY D	O ₂ supply control for isolating either supply line from the fuel cell system	Operable switches with indication to I/C	C → I
CO _{2so}	CRY D	O ₂ supply control for isolating the O ₂ tanks from the manifold	Operable switches with indication to I/C	C → I
CO _{2i}	CRY D	O ₂ isolate control for connecting the tanks manifolds	Operable switches with indication to I/C	C → I

C-6

SID 62-1438

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Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
CS _{is}	CRY D	Cryogenic system indication select (O ₂ tanks or H ₂ tanks)	Multiplex switch in C/M to route selected system readings to meters, selection indication to the I/C	C → I
C _i - c, 1, 2, 3,		Communications, crew members to and from I/C	Instructor may communicate with each crew member individually and vice-versa	I ↔ C
CCL	NAV STA	Computer condition lights, navigation station	Computer controlled as a function of preprogrammed or instructor inserted malfunctions, repeater indications to the I/C	D → C D → I
CDU _{cms}	NAV STA	CDU computer (auto) mode select	Crew activated switch with indication to I/C, control to computer	C → D C → I
CDU _{cmi}	NAV STA	CDU computer (auto) mode indication	Operating mode indication to C/M and I/C	D → C D → I
CDU _{mms}	NAV STA	CDU manual mode select	Crew activated switch with indication to I/C, control to computer	C → D C → I



Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
CDU _{zes}	NAV STA	CDU zero encoder mode select	Crew activated switch with indication to I/C, control to computer	<pre> graph LR C --- S(()) S --> D S --> I </pre>
CDU _{cas}	NAV STA	CDU coarse align mode select	Crew activated switch with indication to I/C, control to computer	<pre> graph LR C --- S(()) S --> D S --> I </pre>
CDU _{fas}	NAV STA	CDU fine align mode select	Crew activated switch with indication to I/C, control to computer	<pre> graph LR C --- S(()) S --> D S --> I </pre>
CDU _{ls}	NAV STA	CDU lock mode select	Crew activated switch with indication to I/C, control to computer	<pre> graph LR C --- S(()) S --> D S --> I </pre>
CDU _{acs}	NAV STA	CDU attitude control mode select	Crew activated switch with indication to I/C, control to computer	<pre> graph LR C --- S(()) S --> D S --> I </pre>
CDU _{mas}	NAV STA	CDU manual align mode select	Crew activated switch with indication to I/C, control to computer	<pre> graph LR C --- S(()) S --> D S --> I </pre>
CDU _{zei}	NAV STA	CDU zero encoder operating mode indication	Computer indication to C/M and I/C of operating mode during automatic computer control	<pre> graph LR D --- S(()) S --> C S --> I </pre>



Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
CDU_{cai}	NAV STA	CDU coarse align operating mode indication	Computer indication to C/M and I/C of operating mode during automatic computer control	
CDU_{fai}	NAV STA	CDU fine align operating mode indication	Computer indication to C/M and I/C of operating mode during automatic computer control	
CDU_{li}	NAV STA	CDU lock operating mode indication	Computer indication to C/M and I/C of operating mode during automatic computer control	
CDU_{aci}	NAV STA	CDU attitude control operating mode indication	Computer condition to C/M and I/C of operating mode during automatic computer control	
$CDU_{\theta_c, \phi_c, \psi_c}$	NAV STA	CDU roll, pitch, yaw angle command (simulated crew gimbal position control)	Crew input to computer driving appropriate CDU modes, instructor station display repeats crew station display	
$CDU_{\theta, \phi, \psi}$	NAV STA	CDU roll, pitch, yaw angle (simulated platform gimbal angle)	Computer driven display during appropriate CDU modes, repeater information to I/C	



Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input-Output
$CDU_{\theta_e, \phi_e, \psi_e}$	NAV STA	CDU roll, pitch, yaw attitude error	Computer driven display—the difference between commanded gimbal angle and present gimbal position, repeater at I/C	
$CDU_{\theta_{si}, \phi_{si}, \psi_{si}}$	NAV STA	CDU roll, pitch, yaw angle manual slew indications	Indication to I/C of crew operation of slew control	$C \longrightarrow I$
$DBA_{\theta, \phi, \psi}$	SCS C	Dead-band adjust roll, pitch, yaw	Active switch - control to A/C, indication to I/C	
$DSIF_1 - 4$	AUD C	Crew member, audio system DSIF mode control	Indication to I/C	$C \longrightarrow I$
ES_{gn}	SCS C	Attitude control, guidance and navigation entry mode select	Active switch—control to A/C, indication to I/C	
ES_{scs}	SCS C	Attitude control, SCS entry mode select	Active switch—control to A/C, indication to I/C	
ECO_{bs1}	BSI	S-I engine cut-off	Digital computer controlled indication to C/M and I/C	
ECO_{bs2}	BSI	S-II booster engine cut-off	Digital computer controlled indication to C/M and I/C	



Table C-1. Functional Systems Integration (Cont.)

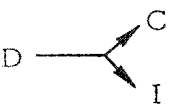
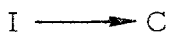
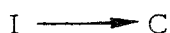
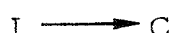


Function	Panel	Description	Panel Status Remarks	Input - Output
ECO _{bs3}	BSI	S-IV booster engine cut-off	Digital computer controlled indication to C/M and I/C	
ECS _{co2}	ECS (gas) display	Carbon dioxide, partial pressure	Meter reading supplied from I/C, it will be adjustable, duplicated at I/C	
ECS _{cp}	ECS (gas) display	Cabin pressure	Meter reading supplied from I/C, it will be adjustable, duplicated at I/C	
ECS _{sp}	ECS (gas) display	Suit inlet manifold pressure	Meter reading supplied from I/C, it will be adjustable, duplicated at I/C	
ECS _{ct}	ECS (gas) display	Cabin temperature	Meter reading supplied from I/C, it will be adjustable, duplicated at I/C	
ECS _{st}	ECS (gas) display	Suit inlet manifold temperature	Meter reading supplied from I/C, it will be adjustable, duplicated at I/C	



Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
ECS _{Δp}	ECS (gas) display	Suit circuit compressor, inlet-outlet differential pressure	Meter reading supplied from I/C, it will be adjustable, duplicated at I/C	I → C
ECS _{scc}	ECS (gas) display	Suit compressor control	Operable switch—position indication to I/C	C → I
ECS _{cbc}	ECS (gas) display	Cabin blower control	Operable switch—position indication to I/C	C → I
ECS _{tc}	ECS (gas) display	Temperature control (cabin or suit)	Operable control—indication to I/C	C → I
ECS _{edt}	ECS (liq) display	Evaporator outlet (steam exhaust line from coolant and air circuit evaporators) temperature	Meter reading supplied from I/C, instructor adjustable, reading duplicated at I/C	I → C
ECS _{cit}	ECS (liq) display	Coolant inlet temperature	Meter reading supplied from I/C, instructor adjustable, reading duplicated at I/C	I → C
ECS _{cot}	ECS (liq) display	Coolant outlet temperature	Meter reading supplied from I/C, instructor adjustable, reading duplicated at I/C	I → C



Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
ECS _{cd}	ECS (liq) display	Coolant discharge volumetric rate	Meter reading supplied from I/C, instructor adjustable, reading duplicated at I/C	I → C
ECS _{cr}	ECS (liq) display	Coolant reserve	Meter reading supplied from I/C, instructor adjustable, reading duplicated at I/C	I → C
ECS _{pc}	ECS (liq) display	Coolant pump control	Operable switch— indication to instructors' duplicate panel	C → I
ECS _{rc}	ECS (liq) display	Radiator control (1 A and B, 2 A and B)	Operable switches— indication to instructors' duplicate panel	C → I
ECS _{wq}	ECS (liq) display	Portable water quantity	Meter reading supplied from I/C, adjustable, duplicate indication at I/C	I → C
EL _{mcr}	ELC	Earth-landing main chute release	Crew control to computer, indication to I/C	C → D C → I



Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
EL _{mcd}	ELC	Earth-landing main chute deploy	Crew control to computer, indication to I/C	
EL _{dmf}	ELC	Earth-landing drogue mortar fire command	Crew control to computer, indication to I/C	
EL _{hsj}	ELC	Earth-landing heat shield jettison	Crew control to computer, indication to I/C	
EL _{a-s}	ELC	Earth-landing system, arm-safe switch	Crew control to computer, indication to I/C	
EL _{ri}	ELC	Earth-landing system, ready indication	Computer indication to C/M and I/C	
FC _{h2fr}	FCD	Fuel cells H ₂ flow rate	Adjustable meter reading supplied from I/C	
FC _{O2fr}	FCD	Fuel cells O ₂ flow rate	Adjustable meter reading supplied from I/C	

C-14

SID 62-1438

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Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
FC _{ph}	FCD	Fuel cell PH sensor information	Adjustable meter reading supplied from I/C	I → C
FC _t	FCD	Fuel cells, temperature sensor display	Adjustable meter reading supplied from I/C	I → C
FC _{rp}	FCD	Fuel cells regulator outlet pressure	Adjustable meter reading supplied from I/C	I → C
FC _{rps}	FCD	Fuel cells regulator outlet pressure (O ₂ , H ₂ , N ₂)	Multiplex switch in C/M switches selected reading to meter, selection indication to I/C	C → I
FC _{ts}	FCD	Fuel cells temperature sensors select (skin, coolant, exhaust)	Multiplex switch in C/M switches selected reading to meter, selection indication to I/C	C → I
FC _{phs}	FCD	Fuel cells PH sensor select	Multiplex switch in C/M switches selected reading to meter, selection indication to I/C	C → I

C-15

SID 62-1438

~~CONFIDENTIAL~~



Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
FC _{frs}	FCD	Fuel cells flow rate select (H ₂ or O ₂)	Multiplex switch in C/M switches selected reading to meter, selection indication to I/C	C → I
FC _{ri}	FCD	Fuel cells reactants isolate control	Operable switch with indication to I/C	C → I
FC _{sa}	FCD	Fuel cells squib arm (1, 2, 3), to fuel cell gas supply shut-off valve	Operable switch with indication to I/C	C → I
FC _{sis}	FCD	Fuel cells, system indication select (fuel cells 1, 2, or 3)	Selects which of 3 fuel cells are displayed and/or affected by panel controls, selection indication to I/C	C → I
FC _{pc}	FCD	Fuel cell purge controls for H ₂ and O ₂	Operable switch with indication to I/C	C → I
FC _{spc}	FCD	Fuel cell system (1, 2, or 3), pump control	Operable switch with indication to I/C	C → I

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Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
GN _{cl}	NAV STA	Guidance and navigation system condition lights	Instructor-controlled indications correlated with appropriately inserted malfunctions	I → C
HF ₁₋₄	AUD C	Crew member audio system HF control	Indication to I/C	C → I
IFTS _{ms}	IFTSSS	In-flight test system, mode-select (off-scan)	Active switch - control to digital computer, indication to I/C	C → D C → I
ID _{fs}	INT D	Integrated display, film select	Indication to I/C	C → I
ID _{pc}	INT D	Integrated display, power control	Indication to I/C	C → I
ID _{ds}	INT D	Integrated display, display select	Control and indication to I/C	C → I
ID _{dc}	INT D	Integrated display, display control	Instructor, from crew selection, controls displayed information	I → C
INTR ₁₋₄	AUD C	Crew member audio system intercom mode control	Indication to I/C	C → I

C-17

SID 62-1438

CONFIDENTIAL



Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
IGN_{bs1}	BSI	S-I booster stage ignition	Digital computer controlled indication to C/M and I/C	
IGN_{bs2}	BSI	S-II booster stage ignition	Digital computer controlled indication to C/M and I/C	
IGN_{bs3}	BSI	S-IV booster stage ignition	Digital computer controlled indication to C/M and I/C	
$IC_{\theta, \phi, \psi}$	NAV STA	Minimum impulse control (roll, pitch, yaw)	Control to analog computer, indication to I/C	
LES_j	BSI	Launch escape system jettison	Digital computer controlled indication, to C/M and I/C	
LO_s	BSI	Lift-off status (hold down - separate)	Digital computer controlled indication, to C/M and I/C	
LVS_{scs}	SCS C	Attitude control SCS local vertical mode select	Active switch - control to A/C, indication to I/C	

Table C-1. Functional Systems Integration (Cont.)



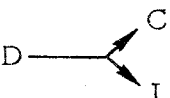
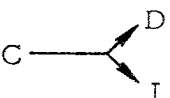
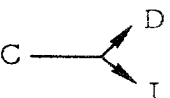
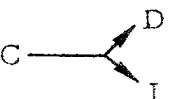
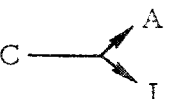
Function	Panel	Description	Panel Status Remarks	Input - Output
LE _{ri}	LEC	Launch escape system, ready indication	Computer indication to C/M and I/C	
LE _{tri}	LEC	Launch escape system, tower released indication	Computer indication to C/M and I/C	
LE _{nri}	LEC	Launch escape system, tower not released indication	Computer indication to C/M and I/C	
LE _{a-s}	LEC	Launch escape system, arm-safe switch	Crew control to computer, indication to I/C	
LE _{sma}	LEC	Launch escape system, motor activate command	Crew control to computer, indication to I/C	
LE _{sta}	LEC	Launch escape system, tower activate command	Crew control to computer, indication to I/C	
MIG _c	SCS PC	Pitch-yaw gyro control (on-off-auto)	Active switch - control to analog computer, indication to I/C	



Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
MA _a	LEC	Manual abort activate	Crew control to computer, indication to I/D	C → <div style="display: inline-block; vertical-align: middle;"> <div style="display: inline-block; width: 10px; height: 10px; border: 1px solid black; margin-right: 5px;"></div> <div style="display: inline-block; width: 10px; height: 10px; border: 1px solid black; margin-right: 5px;"></div> <div style="display: inline-block; width: 10px; height: 10px; border: 1px solid black;"></div> </div>
MTC _i		Manual thrust control (attitude or translation) indication	Indication to I/C signalling the use of manual controls by the crew	C → I
MCL ₁₋₂₀		Master caution lights	Instructor controlled as a function of inserted malfunctions, or computer controlled through I/C as a function of pre-programmed malfunctions	I → C
MF _{cc1}		Computer controlled malfunctions	Computer control through I/C to C/M	D → I
MF _{cc2}		Preprogrammed or instructor inserted malfunctions, control by digital computer of analog computer simulation malfunctions	Computer control through analog computer of preprogrammed or instructor-inserted malfunctions	D → A

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Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
MC		Mission control (off-standby-start-stop)	Instructor control of computer complex for training mission execution	I → D
MF _{ic1, ic2}		Instructor-controlled malfunctions	Malfunction control by instructor through digital computer	I → D
MS _{si}		Training complex system status indicators	Computer indications to instructor of system readiness parameters	D → I
MF _i		Malfunction indicators	Crew indicators energized as a result of direct instructor-inserted malfunctions, malfunctions preprogrammed or instructed through the computers, or, malfunctions computer controlled through the I/C	I → C
PD _{fcc}	PD D1	Power distribution fuel cell control, BUS A: 1, 2, 3, off-on BUS B: 1, 2, 3, off-on	Switches will be directly connected to I/C, where switch position will be indicated on a duplicate panel	C → I

C-21

SID 62-1438

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Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
PD _{bbc}	PD D1	Power distribution, battery bus control BUS A: on-off BUS B: on-off BUS C: on-off	Switches will be directly connected to I/C, where switch position will be indicated on a duplicate panel	C → I
PD _{gpc}	PD D1	Power distribution, ground power control BUS A: on-off BUS B: on-off	Switches will be directly connected to I/C, where switch position will be indicated on a duplicate panel	C → I
PD _{ct}	PD D3	Power distribution, component temperature	Meter readings supplied from I/C, capability for instructor adjustment of reading will be provided	I → C
PD _{vac}	PD D3	Power distribution, volts, ac	Meter readings supplied from I/C, capability for instructor adjustment of reading will be provided	I → C
PD _f	PD D3	Power distribution frequency	Meter readings supplied from I/C, capability for instructor adjustment of reading will be provided	I → C

Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
PD _{cts}	PD D3	Power distribution, component temperature select	Multiplex switch in C/M routes selected reading to meter, selection indicated on instructor station duplicate panel	C → I
PDI _{acs}	PD D3	Power distribution inverter — a-c bus select a-c BUS 1: 1, 2, 3 a-c BUS 2: 1, 2, 3	Crew selection indicated at I/C	C → I
PDI _{acr}	PD D3	Power distribution inverter, a-c bus readings	Readings supplied by I/C, instructor adjustable	I → C
PD _{bis}	PD D3	Power distribution, bus indicated select	Selects appropriate a-c bus readings for meter, indication to I/C	C → I
PDI _{dci}	PD D3	Power distribution select, d-c input to inverter	Indication to I/C	C → I
PD _{bcs}	PD D3	Power distribution, select batteries for charge	Indication to I/C	C → I

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Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
PD _{ps}	PD D3	Power distribution, select a-c phase for meter display	Multiplex switch in C/M routes selected readings to appropriate meters, indication to I/C	C → I
PD _{acf}	PD D3	Power distribution, a-c bus failure	Instructor controlled indication	I → C
PD _{loh}	PD D3	Power distribution, inverter overheat	Instructor controlled indication	I → C
PD _{vdc}	PD D2	Power distribution, d-c voltage	Meter readings supplied from I/C, capability for instructor adjustment will be provided	I → C
PD _{cdc}	PD D2	Power distribution, d-c current	Meter readings supplied from I/C, capability for instructor adjustment will be provided	I → C
PD _{is}	PD D2	Power distribution, indicator select, (fuel cell 1, 2, and 3, batteries A, B, and C, main bus A and B, battery charger, or post-landing bus)	Multiplex switch in the C/M routes appropriate reading to meter, selected quantity indicated at I/C duplicate panel	C → I

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Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
PD_{uvr}	PD D2	Power distribution, under voltage reset	Reset control to I/C to override instructor-inserted under-voltage indication	$C \longrightarrow I$
PD_{uvi}	PD D2	Power distribution, under voltage indication	Instructor-controlled indication	$I \longrightarrow C$
PD_{bc}	PD D2	Power distribution, battery control	Crew selection indicated at I/C on a duplicate panel	$C \longrightarrow I$
$PS_{hra, b}$	SPD	Helium regulator control	Crew control to analog computer, indication to I/C	$C \begin{array}{l} \nearrow A \\ \searrow I \end{array}$
PF_q	SPD	Propulsion fuel quantity	Analog controlled function	$A \begin{array}{l} \nearrow C \\ \searrow I \end{array}$
PO_q	SPD	Propulsion oxidizer quantity	Analog controlled function	$A \begin{array}{l} \nearrow C \\ \searrow I \end{array}$
PS_{fm}	SPD	Propulsion system fuel mixture	Crew controlled function to analog computer, indication to I/C	$C \begin{array}{l} \nearrow A \\ \searrow I \end{array}$

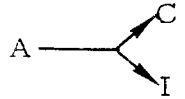
C-25

SID 62-1438

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Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
PR	SPD	Propellant ratio	Analog computer driven under crew control, duplicate indication to I/C	
PF _{tp}	SPD	Fuel tank pressure	Instructor adjustable reading from I/C	I → C
PO _{tp}	SPD	Oxidizer tank pressure	Instructor adjustable reading from I/C	I → C
PF _{ip}	SPD	Fuel inlet pressure	Instructor adjustable reading from I/C	I → C
PO _{ip}	SPD	Oxidizer inlet pressure	Instructor adjustable reading from I/C	I → C
PH _{tp}	SPD	Helium tank pressure	Instructor adjustable reading from I/C	I → C
PH _{tt}	SPD	Helium tank temperature	Instructor adjustable reading from I/C	I → C
PS _{qdc}	SPD	Propulsion system quantity display control	Multiplex switch to select reading, selection indication to I/C	C → I
PCM _{fs}	TC	Telecommunications system PCM format selection (3 states)	Operable switches with indication to I/C	C → I

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Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
RA _{s-iv}	SC	Separation control, S-IV retro activate	Crew control to computer, indication to I/C	
RA _{sm}	SC	Separation control, SM retro activate	Crew control to computer, indication to I/C	
RA _{lem}	SC	Separation control, LEM retro activate	Crew control to computer, indication to I/C	
RTG _c	SCS PC	Rate gyro control, (on-auto-off)	Active switch - control to analog computer, indication to I/C	
RG _{pc}	SCS PC	Rate gyro control, (on-auto-off)	Active switch - control to analog computer, indication to I/C	
RS _{bs3}	BSI	S-IV booster restart	Digital computer controlled indications, to C/M and I/C	
RH _{tpa, b, c, d}	RCD	Reaction control system, helium tank pressure	Instructor adjustable reading from I/C	

C-27

SID 62-1438

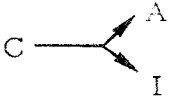
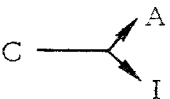
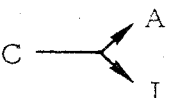
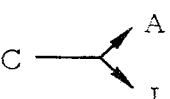
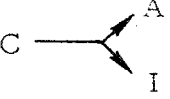
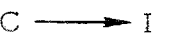
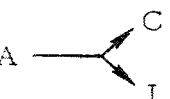
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Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
RHR _{opa, b, c, d}	RCD	Reaction control system, helium regulator outlet pressure	Instructor adjustable reading from I/C	I → C
RS _{pta, b, c, d}	RCD	Reaction control system, package temperature	Instructor adjustable reading from I/C	I → C
RF _q	RCD	Reaction control system, fuel quantity	Analog controlled function, reading to C/M and I/C	A → C I ← C
RO _q	RCD	Reaction control system, oxidizer quantity	Analog controlled function, reading to C/M and I/C	A → C I ← C
RCS _{ica, b, c, d}	RCD	Reaction control system, propellant isolate control	Crew controlled function to analog computer, indication to I/C	C → A C → I
RCS _{dsa, b, c, d}	RCD	Reaction control system, display system, A, B, C, or D	Multiplex switch to C/M to select displayed quantities, selection indication to I/C	C → I
RCS _{mfa, b, c, d}	RCD	Reaction control system, malfunction indication	Analog computer indication to C/M and I/C as a function of inserted malfunctions	A → C A → I

Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
RCS _{ss}	RCD	Reaction control system, select (C/M or S/M)	Crew control to analog simulation of RCS, indication of selection to I/C	
RSA _{fc}	RCD	Reaction system, C/M activation— fire command	Crew control to analog simulation of RCS, indication of selection to I/C	
RSA _{a-s}	RCD	Reaction system, C/M activation-arm-safe switch	Crew control to analog simulation of RCS, indication of selection to I/C	
RE _{dcl}	EMI	Reentry display control, (start-stop, reset)	Crew control to analog computer, indication to I/C	
RE _{dc2}	EMI	Reentry display control (auto-off, override)	Crew control to analog computer, indication to I/C	
RE _{dc3}	EMI	Reentry display control (calibrate)	Repeater indication to I/C	
RE ₁	EMI	Reentry display lift	Control from analog computer, indication to C/M and I/C	

C-29

SID 62-1438

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Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
RE _g	EMI	Reentry display, gravity loading	Control from analog computer, indication to C/M and I/C	
RE _{dd}	EMI	Reentry display, display drive	Control from analog computer, indication to C/M and I/C	
SCS _m	SCS C	Attitude control, monitor mode select	Active switch - control to analog computer, indication to I/C	
SEP _{bs1}	BSI	S-I booster separation	Digital computer con- trolled indication to C/M and I/C	
SEP _{bs2}	BSI	S-II booster separation	Digital computer con- trolled indication to C/M and I/C	
SEP _{bs3}	BSI	S-IV booster separation	Digital computer con- trolled indication to C/M and I/C	
SC _r	SC	Separation control, ready indication	Computer indication to C/M and I/C	

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SPACE and INFORMATION SYSTEMS DIVISION

Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
SC _{c/m} and s/m	SC	Command module— service module separation control	Crew control to com- puter, indication to I/C	C — Y ^D / _I
SC _{lem}	SC	Separation control, lunar excursion module	Crew control to com- puter, indication to I/C	C — Y ^D / _I
SC _{baj}	SC	Separation control, service module booster adapter jettison	Crew control to com- puter, indication to I/C	C — Y ^D / _I
SC _{bas}	SC	Separation control, booster adapter separation (service module)	Crew control to com- puter, indication to I/C	C — Y ^D / _I
SC _{a-s}	SC	Separation control, arm-safe switch	Crew control to com- puter, indication to I/C	C — Y ^D / _I
SM _{sj}	SC	Separation control, service module shroud jettison	Crew control to com- puter, indication to I/C	C — Y ^D / _I
SM _{pa}	SC	Separation control, S/M posigrade	Crew control to com- puter, indication to I/C	C — Y ^D / _I

C-31

SID 62-1438

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Table C-1. Functional Systems Integration (Cont.)

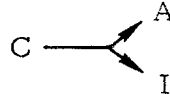
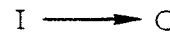
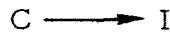

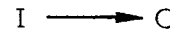
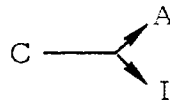
Function	Panel	Description	Panel Status Remarks	Input - Output
SCS _{pc}	SCS PC	Stabilization and control system power control	Active switch - control to analog computer, indication to I/C	
SM _{qtr}	S/M QTI	Service module quadrant temperature reading	Reading supplied from the I/C, adjustable, duplicated at I/C	
SM _{qts}	S/M QTI	Service module quadrant temperature - quadrant select	Multiplex switch in C/M to select appropriate quadrant, selection indicated at I/C	
T	CTI	Precision time signal (1 pulse/second)	Common time signal from the digital computer to all digital-type clocks in C/M and at I/C	
T _{cw}	SPD	Chamber wall temperature "HI"	Instructor-controlled indication	
T _{ec}		Translation axes' emergency control	Crew activation causes manual commands to be routed directly to reaction jets, indication of emergency mode to I/C	



Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
TM _{ao}	NAV STA	IMU temperature mode, select auto-override mode	Control indication of selection to I/C	C → I
TM _p	NAV STA	IMU temperature mode, select proportional mode	Control indication of selection to I/C	C → I
TM _b	NAV STA	IMU temperature mode, select back-up mode	Control indication of selection to I/C	C → I
TM _e	NAV STA	IMU temperature mode, select emergency mode	Control indication of selection to I/C	C → I
TC _{as}	NAV STA	IMU temperature control circuits, adjustment select (zero-gain)	Selection indication to I/C	C → I
TC _{ai}	NAV STA	IMU temperature control circuits, adjustment indication	Indication to I/C	C → I
T _{ms}	TC	Telecommunications system mode select (7 modes)	Operable switches with indication to I/C	C → I



Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
T _{pc}	TC	Telecommunications system power control (5 states)	Operable switches with indication to I/C	C → I
T _{oc}	TC	Telecommunications system oscillator control (3 states)	Operable switch with indication to I/C	C → I
T _{rc}	TC	Telecommunications system tape recorder control (6 controls)	Operable switch with indication to I/C	C → I
T _{rss}	TC	Telecommunications system recovery systems select and controls (3 controls)	Operable switch with indication to I/C	C → I
T _{sec}	TC	Telecommunications system systems equipment control (6 controls)	Operable switch with indication to I/C	C → I
VHF-AM ₁₋₄	AUD C	Crew member audio system VHF -AM mode control	Indication to I/C	C → I
V _{pc}	NAV STA	Viewer power control	Indication to I/C of viewer status (ON-OFF)	C → I

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Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
V_{fs}	NAV STA	Viewer film selector	Indication to I/C of crew-selected film	$C \longrightarrow I$
V_{ds}	NAV STA	Viewer display selection	Indication to I/C of crew selection of discreet display contained on selected film. (This enables the instructor to set up his display to correspond with the crew display)	$C \longrightarrow I$
XTR_{1-4}	AUD C	Crew member audio system transmitter mode control	Indication to I/C	$C \longrightarrow I$
$\dot{X}C_t, \dot{Y}C_t, \dot{Z}C_t$		X, Y, Z, axis control command	Left armrest control at control station and center station in C/M	$C \longrightarrow A$
ΔVS_{gn}	SCS C	Attitude control, guidance and navigation system ΔV mode select	Active switch—control to analog computer, indication to I/C	$C \longrightarrow \begin{matrix} A \\ I \end{matrix}$
ΔVS_{scs}	SCS C	Attitude control, SCS system ΔV mode select	Active switch—control to analog computer, indication to I/C	$C \longrightarrow \begin{matrix} A \\ I \end{matrix}$

C-35

SID 62-1438

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Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
ΔV_{ufc}	ΔVD	Emergency ullage, fire command	Crew command to analog computer	C \longrightarrow A
ΔV_{ufi}	ΔVD	Emergency ullage, fire indication	Crew command indication to I/C	C \longrightarrow I
ΔV_{efc}	ΔVD	Engine fire command	Crew or automatic command to analog computer	manual C \longrightarrow A
ΔV_{efi}	ΔVD	Engine fire indication	Command indication to I/C	automatic D \longrightarrow C I \longleftarrow automatic and manual
ΔV_{eco}	ΔVD	Engine cut-off	Crew or automatic command to analog computer, indication to I/C	D com A com C \longrightarrow I ind
ΔV_{ir}	ΔVD	Integrator reset	Crew command to digital computer, indication to I/C	C \longrightarrow D com I ind
ΔV_{rq}	ΔVD	Required velocity setting	Crew setup information to digital computer repeater, indication to I/C	C \longrightarrow D I

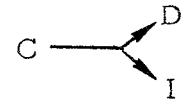
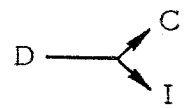
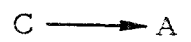


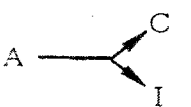
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Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
ΔV_{tv}	ΔVD	Tail-off correction setting	Crew setup information to digital computer repeater, indication to I/C	
ΔV_r	ΔVD	Velocity correction remaining	Digital computer drive to countdown velocity correction	
$\delta \theta_c, \psi_c$	GPI	Propulsion engine pitch and yaw gimbal angle command	Crew control to analog computer simulation of the engine gimbal control loop	
$\delta \theta, \psi$	GPI	Propulsion engine pitch and yaw gimbal angle	Indication of engine gimbal position to C/M and I/C from analog simulation of gimbal control loop	
θ, ϕ, ψ	FDAI	Roll, pitch and yaw attitude	Drive signal to C/M and I/C from analog computer simulation of SCS or guidance and navigation	
$\dot{\theta}, \dot{\phi}, \dot{\psi}$	FDAI	Roll, pitch and yaw attitude rate	Drive signal to C/M and I/C from analog computer simulation of SCS or guidance and navigation	

C-37

SID 62-1438

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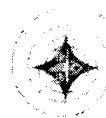


Table C-1. Functional Systems Integration (Cont.)

Function	Panel	Description	Panel Status Remarks	Input - Output
θ_E, ϕ_E, ψ_E	FDAI	Roll, pitch and yaw attitude error	Drive signal to C/M and I/C from analog computer simulation of SCS or guidance and navigation	<pre> graph LR A --> C A --> I </pre>
$\theta_{C_a}, \phi_{C_a}, \psi_{C_a}$	FDAI	Roll, pitch, and yaw axis attitude control command	Right armrest control at control station and center station in C/M. Provisions for use at navigation station	<pre> graph LR C --> A </pre>